Oils, Fats, and Fuels

OILS, FATS, AND FUELS

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PREFACE

This book is intended for the use of students in Day and Evening Technical Schools and Classes. Every endeavour has been made to place before the student who requires a good general knowledge of the subjects included, as full information as space permits.

It does not profess to be a work on pure chemistry, and, except in one or two cases, chemical formulæ and equations have been purposely omitted. It is hoped, however, that nothing of importance has been left out, and that the book will be found useful to teachers and students.

The writer wishes to express his deep obligation for the invaluable assistance he has received, and desires to thank his colleagues, J. W. Hepple, Esq., B.Litt., for the drawings for Figures 1, 2, 5, 6, 20, 26, 27, and D. R. Davies, Esq., for the drawing for Figure 25, and the following manufacturers and firms for drawings, photographs, and descriptive matter:

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OILS AND FATS

FUELS

Questions on Chapter I

1. Why is sugar a fattening food?

2. The solidifying-point of olive oil is 2° C. If a test-tube containing a small quantity of olive oil were placed upright in broken ice, what would happen?

3. Cane sugar contains 6·43 per cent of hydrogen. What weights of hydrogen and oxygen are contained in 1 ton of cane sugar?

4. What are palmitin, stearin, and olein?

5. The melting-point of palm oil is 35° C. Is it a liquid or a solid in this country?

6. Where do fatty oils and solid fats occur in nature?

CHAPTER II

Properties of Fatty Oils and Solid Fats

Effect on our Senses.—In their pure state fatty oils and solid fats are colourless, tasteless, and odourless. What is usually regarded as their characteristic colour, taste, or smell is really due to the presence of extremely small quantities of foreign substances.

Specific Gravity.—Their specific gravities vary between the limits 0·91 and 0·97.

Freezing-point or Solidifying-point.—The freezing-points of those fatty oils which are fluid at the ordinary temperature, range from a few degrees above 0° C. to − 28° C.

Solubility in Water.—In their fresh state they may be considered as being completely insoluble in pure water, although traces are dissolved when oils are shaken with large quantities of water.

Effect of other Solvents.—With the exception of castor oil, they dissolve but very sparingly in cold alcohol. Boiling alcohol, however, dissolves larger quantities, but on cooling nearly all the fat or oil separates out. They are readily soluble in ether, carbon bisulphide, benzene, chloroform, petroleum and paraffin oils. Castor oil forms an exception as regards petroleum and paraffin oils.

Effect of Heat.—Dry oils and fats undergo no loss when heated to a temperature of 150° C. Provided prolonged contact with air is avoided, most of these bodies can be heated to 250° C. without undergoing any chemical change. When the heating is continued beyond 250° C., decomposition sets in, with the formation of volatile products, the most prominent being acrolein.

The intense odour of acrolein, which all fats emit on being heated above 300° C., is one of the most characteristic reactions, enabling one rapidly to distinguish this group of oils and fats from mineral oils. Whenever a tallow candle or a lamp burning a fatty oil is blown out, the well-known penetrating smell of acrolein is always present.

Action of Oils on Paper.—In their liquid state fats penetrate easily into the pores of dry substances. If dropped on paper they leave a translucent spot (grease spot), which cannot be removed by washing with water and subsequent drying. A body which allows light to pass through it, but through which objects cannot be distinctly seen, is said to be translucent.

Action of Air.—On exposure to the atmosphere, oils and fats gradually undergo certain changes. The change produced is most marked in the case of the drying oils, which unite with oxygen just as iron does when it oxidizes. Drying oils thicken at first, and then form an elastic skin on the surface.

Linseed oil, if left simply exposed to the air, will take up a considerable quantity of oxygen, as is shown by the fact that it gains in weight to the extent of perhaps 20 per cent. This absorption of oxygen by drying oils is a chemical action, and, like other cases of oxidation, is accompanied by the production of heat. If the oil were spread out on a plate to dry, the heat would be easily dissipated. If, however, cotton waste be smeared with a drying oil, the conditions are favourable for very rapid oxidation, on account of the large surface of oil exposed to the air. Material like cotton waste or rags is also a bad conductor of heat, and the heat which results from the oxidation of the oil accumulates so rapidly that spontaneous combustion will ensue. Heaps of cotton waste impregnated with oil have been known to ignite spontaneously.

Non-drying oils remain more or less unchanged in appearance and composition when exposed to the air, while semi-drying oils occupy an intermediate position.

Rancidity of Oils and Fats. —When non-drying oils and fats are exposed to the simultaneous action of air, moisture, and light, they become rancid. Oils turn rancid more rapidly than solid fats. Rancidity cannot be detected by chemical means, and the taste and smell are the best means of finding whether a fat or an oil is rancid or not.

Fig. 2. Separating Funnel

EXPERIMENT 2.—*To test the solu bility of olive oil in water.*

Shake up about 20 c. c. of distilled water with 5 c. c. of olive oil. Pour into a small separating-funnel (fig. 2) and allow the emulsion to stand, when it separates into two layers (water below, oil above). Run off the water and filter it. Shake the
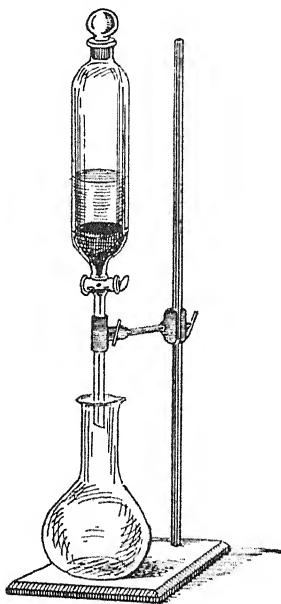
filtrate with ether; allow to stand to separate (water below, ether above). Transfer the ether to an evaporating-basin by means of a pipette and allow it to evaporate in a draught cupboard without applying heat. The small quantity of olive oil, which was dissolved by the water, is left in the basin.

EXPERIMENT 3.—*To test the solubility of oils and fat· in other solvents.*

Test the solubility of lard and olive oil in ether, carbon bisulphide, benzene, and paraffin oil. To do this, place 5 c. c. of each solvent in separate test-tubes, and place in each solvent a piece of lard as large as a small pea. Shake and note the result. Repeat with 5 c. c. of each solvent, to which has been added 6 drops of olive oil. Shake and note result.

EXPERIMENT 4.—*To find the effect of oil on paper.*

Make a grease spot on a sheet of white paper, and hold it between your eye and a light, and the spot appears brighter than the rest of the paper. Greasing the paper makes it more transparent, therefore more light passes through the greased part. Now stand with your back to the light and allow the light to fall on the paper. The grease spot appears darker than the rest of the sheet, because it now lets through more light than the ungreased part does. Therefore it cannot reflect as much light to the eye, hence the spot appears darker.

QUESTIONS ON CHAPTER II

1. What happens when a fatty oil and water are shaken together and then allowed to stand?

2. Why does benzene remove grease stains from clothes?

3. Why cannot fatty oils be purified by distillation?

4. The specific gravity of linseed oil is 0·93. Find its density in pounds per cubic foot. Density of water = 62·3 lb. per cubic foot.

5. Why is it dangerous to allow heaps of oily waste to accumulate in a factory?

6. Why does butter turn rancid?

CHAPTER III

Commercial Production of Oils and Fats

The appliances used for the production of oils and fats range from the simplest contrivances up to the most elaborate machinery. Some of the oldest methods still survive to-day, though they are rapidly being replaced by more up-to-date processes. The methods employed for the production of these substances divide themselves naturally into three groups:

I. By "rendering".
II. By "expression".
III. By the aid of solvents.

I. Preparation of Oils and Fats by "Rendering"

Formerly animal oils and fats were obtained by heating in a vessel, over fire, those parts of the animal which contained oil or fat. This old-fashioned method is obsolete in large establishments, but in smaller works it is still carried on, especially on the Continent. In order to carry out the rendering of tallow and other fats, so that no objection can be raised from a sanitary point of view, a number of forms of apparatus have been designed, in which the fatty parts are melted in closed vessels, by steam under pressure. These vessels are called Digesters, and consist of a vertical boiler provided with a false perforated bottom, and tested to stand a pressure of several atmospheres. Steam under pressure is led into the boiler, below

the perforated bottom on which the fat rests, and
the steam melts the fat out of the animal tissues.
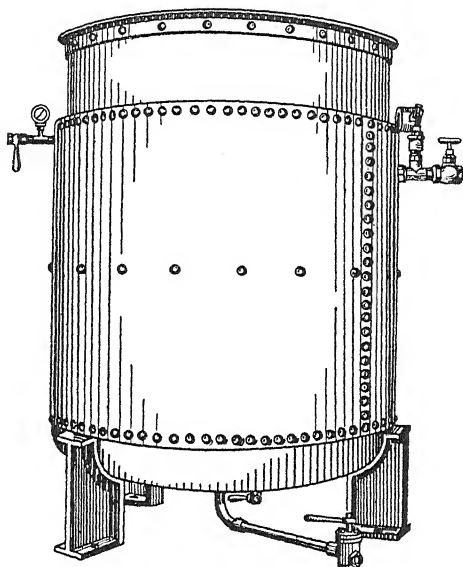
Fig. 3.—Digester for rendering Animal Fats

"Rendering" is applied on the large scale to the
production of animal oils and fats.

II. Preparation of Oils and Fats by "Expression"

The invention of the hydraulic press in 1795, by
Joseph Bramah, brought about a great revolution in
the oil industry, as it introduced a new and almost
unlimited source of power. This invention was very
much assisted, during the nineteenth century, by
the invention of the hydraulic accumulator by I   ·¹
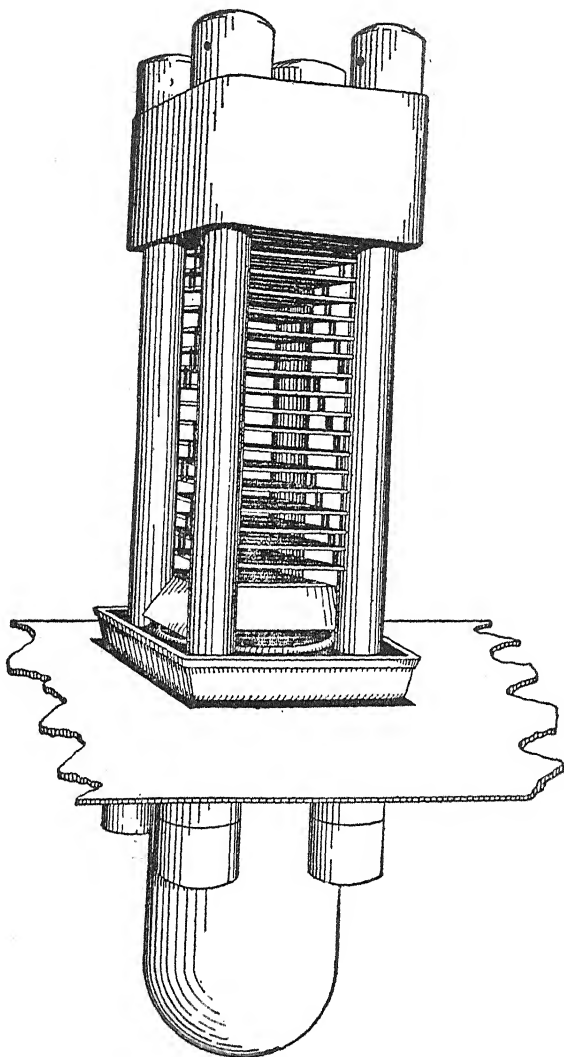
Fig. 4.—Hydraulic Oil Press

Armstrong.   On account of these two inventions, England took first place in this industry up to the end of the nineteenth century.   Expression is applied principally to the production of vegetable oils.   The operations carried out in expressing oil from oil seeds, oil nuts, and other vegetable matter are as follows:

The seeds and nuts are freed from dust, sand, and other foreign bodies.   They are then decorticated (shelled) if necessary, the shells being removed by mechanical means, and the kernels are converted into meal by passing through rollers.   For preparing edible fats and oils the meal is pressed in the cold state, under a pressure of 300 atmospheres or more (2 tons or more per square inch).   Prepared in this way, they are known as cold-drawn or cold-pressed oils.   To obtain more oil, the temperature of the pressed cake is raised and the operation repeated, but oils thus obtained are employed for manufacturing purposes.   When the seeds contain over 40 per cent of oil, it is always necessary to repeat the pressure.

Nowadays vertical presses are always used, and a common type of hydraulic press used is shown in fig. 4.   The pressure chamber, above the ram, is fitted with from 12 to 18 mild-steel corrugated press plates, between which the layers of meal or broken seed are inserted.

With such a press the gross pressure employed is about 800 tons.   The size of the cakes of meal produced is about 12 in. by 30 in.   When seed is undergoing pressure, the oil runs down the outside of the press and is collected in a trough fixed to the base.

III. Extraction of Oils and Fats by means of Volatile Solvents

Extraction of oil from seeds by means of volatile solvents was first carried out in this country in 1843. If it be desired to obtain larger quantities of oils and

fats than can be obtained by expression, the extraction must be carried out by making use of the solvent properties of liquids. Not only pressed seed is treated in this way, but it is also largely used to extract the oil from fresh seed. Fresh seed employed for extraction with solvents is not reduced to such a fine meal as in the case of expression, as this would make too compact a mass, and so prevent the liquid from passing through it.

Solvents used.—Up to comparatively recent times, the solvents used on the large scale were almost entirely carbon bisulphide and petroleum spirit. Both these liquids have a great disadvantage, in that they are readily inflammable.

Carbon Bisulphide.—This was the liquid first employed. It is mobile and heavier than water, its relative density being 1·29. It boils at 46° C., and at ordinary temperatures gives off a heavy inflammable vapour.

Petroleum Spirit and Paraffin Naphtha.—These liquids were first used for oil extraction in 1863. They are mobile liquids obtained from petroleum and shale oil respectively. They boil about 115° C. and have a relative density of 0·75. They are preferable to carbon bisulphide, and are largely used in the extraction of linseed oil and rape oil.

Ordinary Ether.—The boiling-point of this liquid is 35° C., hence it is too volatile and therefore too dangerous to be largely used.

Chloroform and Benzene.—These liquids are too expensive, besides having other drawbacks.

Carbon Tetrachloride. — During recent years this liquid has been introduced. It is heavier than water, its relative density being 1·63, and its boiling-point is 76° C. Its chief advantage is that it is non-inflammable.

Principle of Extraction.—The principle of extraction is illustrated by fig. 5, where the crushed seed is placed in A, a suitable quantity of the solvent being placed in the flask B. On heating this by a water-bath the solvent is vaporized, and passes through the

tube C and the upper part of A to a condenser D (end shown), which returns the condensed liquid on to the seed, through which it slowly percolates, dissolving out the oil on its way. After the seed has been exhausted, the solvent in B contains the oil in solution. This solution is then transferred to a still heated by steam, where the solvent is driven off and recovered by condensing the vapour, to be used again and again.

Fig. 5.—Apparatus to illustrate the Principle of Extraction with Solvents

Advantages and Disadvantages of the last two processes.—The extraction process with solvents cannot be used for the preparation of edible oils and fats, as it is impossible to get rid of the last traces of the solvent. Extracted oils and fats can therefore only be used for technical purposes. The meal left after extraction is also tainted with the solvent, which makes it unfit for cattle feeding, its proper use being for manuring land.

In some cases, notably in the manufacture of olive oil, a combination is used, most of the oil being first expressed for edible purposes. The oil left in the press cakes is then recovered by extraction and used for other purposes. On the Continent this is known as the mixed process.

Expression is free from danger, while extraction involves risks of fire, if inflammable solvents are used.

COMMERCIAL PREPARATION OF WAXES

The most important waxes, from a commercial point of view, are spermaceti and sperm oil. They are prepared on the large scale in the same manner as the animal fats and oils. Wool wax or lanoline is a wax prepared from the grease of sheep's wool.

EXPERIMENT 5.—*To obtain tallow from suet by "rendering"*.
Procure three pieces of beef or mutton suet, each about the size of a walnut. Place them in a porcelain evaporating-basin, and heat the basin carefully on a tripod stand, provided with wire gauze, using a small flame. After ten minutes, pour off the resulting liquid into a dry clean vessel, and allow to cool, when it forms tallow. The membranes from which the fat was melted are left in the basin.

EXPERIMENT 6.—*To express oil from linseed meal*.
Place about 10 gm. of linseed meal on a piece of calico about 3 in. square, and roll it up compactly. Place it between the jaws of a good vice and tighten up with the handle. Some of the oil is expressed and the calico becomes soaked with linseed oil. This illustrates the expression of oil.

EXPERIMENT 7.—*To extract oil from linseed meal by means of carbon bisulphide.*
Fold and place a filter paper in a funnel on a filter stand. Place on the filter paper about 10 gm. of linseed meal. Pour a small quantity of cold carbon bisulphide over the meal, and catch the liquid which passes through in a test-tube. Pour this again over the meal, repeating about half a dozen times. Place the carbon bisulphide in an evaporating-basin, and set aside in a draught cupboard to evaporate, without the application of heat. The solvent evaporates, leaving a small quantity of linseed oil in the basin.

QUESTIONS ON CHAPTER III

1. What do you understand by cold-drawn castor oil?

2. Taking atmospheric pressure as 15 lb. per square inch, find, in tons per square inch, the pressure which corresponds to 200 atmospheres.

3. Name three of the commonest solvents used in the extraction of oils from vegetable substances.

4. Sketch a hydraulic press as used in the oil industry.

5. If the diameter of the ram of an oil press is 15 in., and the pressure exerted is 400 atmospheres, find the total pressure exerted by the ram.

6. Which method is used for preparing linseed oil, tallow, olive oil?

CHAPTER IV

Vegetable Oils

The fatty oils obtained from vegetables are subdivided as follows:

	1. *Drying Oils.*	*Linseed Oil.* *Hemp-seed Oil.* *Walnut Oil.* *Soya-bean Oil.* *Poppy-seed Oil.*
Vegetable Oils.	2. *Semi-drying Oils.*	*Cotton-seed Oil.* *Sesamé Oil.* *Croton Oil.* *Rape-seed Oil.*
	3. *Non-drying Oils.*	*Arachis Oil.* *Hazel-nut Oil.* *Olive Oil.* *Castor Oil.*

1. DRYING OILS

The drying oils possess the property of absorbing oxygen from the atmosphere, and drying to an elastic skin, when exposed to the air in thin layers.

Linseed Oil

Source and Preparation.—This oil is obtained from the seed of the flax plant. On the average, linseed

contains about 35 per cent of oil. The oil expressed at the ordinary temperature is of a golden yellow colour and has a pleasant taste. Large quantities are used for edible purposes in Russia and Germany, but by far the largest quantities of this oil are employed in the arts. The press cakes, known as linseed cake, retain about 10 per cent of the oil and form a valuable cattle food.

Properties. — Its specific gravity is 0·93 and its solidifying-point is −20° C. On exposure to the air in a thin film on a large surface, it rapidly absorbs oxygen and dries. Its commercial value depends on its drying power. A good raw oil should dry in less than three days; it should not be tacky on touching with the fingers, and should yield an elastic coherent skin. No other drying oil approaches linseed oil in drying power.

Uses. —

1. For edible purposes.

2. For making paints, varnish, putty, linoleum, and oil-cloth.

3. Inferior oils are used for making soft soap.

Soya-bean Oil

Source and Preparation. — This oil, known also as bean oil and Chinese bean oil, is obtained from the seeds of a plant which has been cultivated in China for more than 4000 years. It also grows successfully in Japan, India, and the West Coast of Africa. Soya beans contain about 18 per cent of oil and yield 12 per cent with the press.

The bulk of this oil is produced by expression, but a further considerable quantity is obtained by extracting the residual oil from the pressed meal by solvents.

Properties.—Its specific gravity is 0·924 at 15° C., and it turns solid about −15° C. It requires four days for drying, and even then it is still "tacky".

Uses.—

1. For edible purposes.

2. Has largely replaced linseed oil in making soft soap.

3. For making varnish and paint.

2. SEMI-DRYING OILS

The oils in this class stand between the true drying oils and the non-drying oils. As a rule they possess distinct drying properties, which are much less pronounced, however, than in the case of the true drying oils. Their drying power is increased by allowing them to dry above the ordinary temperature of the air.

Cotton-seed Oil

Source and Preparation.—Cotton-seed oil comes from the seed of the cotton plant, which is largely grown in the United States, India, and Egypt. The seed contains 20 per cent of oil and is subjected to hydraulic pressure.

Properties. — The refined oil has a pale yellow colour, and is quite suitable for edible purposes. Its specific gravity is 0·924 and its solidifying-point 4° C. At the ordinary temperature it forms a viscous mass after exposure to the atmosphere for several weeks in a thin layer. On account of its drying and gumming properties it cannot be used as a lubricating oil. Being one of the cheapest oils it is not liable to adulteration.

Uses.—

1. The finest grades are used as table oil.
2. For making margarine and artificial lard.
3. The lower grades are used for soap-making.

Sesamé Oil

Source.—This oil is obtained from the seeds of the sesamé plant, which is an annual from 2 to 4 feet high, and grows in India, China, Japan, and the West Coast of Africa.

Preparation and Properties.—The seed is rich in oil, containing 55 per cent, and has to be subjected to repeated expression. Its specific gravity is 0·924 and it solidifies at −5° C. The drying power of this oil is not so pronounced as that of cotton-seed oil.

Uses.—

1. As a table oil and for making margarine.
2. Used for illuminating purposes.
3. Lower grades are used in soap-making.

Rape-seed Oil (Colza Oil)

Source and Preparation.—Obtained from the seed of the rape plant, which belongs to the cabbage family. The oil is either expressed or extracted with solvents, and as a rule the extracted oil is purer than the expressed oil. Rape seed contains, on the average, 38 per cent of oil.

Properties and Uses. — The refined oil is pale yellow, and has a characteristic smell and harsh taste. The crude oil is very dark in colour. The specific gravity of colza oil is 0·916 and its solidifying-point is −10° C.

Its drying powers are not very pronounced; when exposed to the atmosphere for seven days it absorbs a small amount of oxygen without really drying, and at the same time it turns rancid. It is therefore a connecting link between the semi-drying oils and the non-drying oils.

In India and on the Continent the cold-drawn oil is used for edible purposes. It is also used for illuminating purposes, and large quantities are employed for lubricating purposes.

3. NON-DRYING OILS

The property of not drying only holds good for these oils at the ordinary temperature, at higher temperatures they thicken and become viscous.

Arachis Oil

Source.—Arachis oil is prepared from the nuts of the arachis plant. The nuts are popularly known as "monkey nuts", other names being ground nuts, earth nuts, and peanuts. The plant grows in tropical and subtropical countries.

Preparation.—The kernels contain 45 per cent of oil. The nuts are shelled and the red skins removed from the kernels. The cleaned kernels are then ground and the oil expressed in three stages — first at the ordinary temperature, the second at 30° C., and the third at 50° C.

Properties and Uses.—The cold-drawn oil is nearly colourless and has a pleasant taste resembling kidney beans; it is used as a salad oil. That obtained by the second and third expressions is used for making margarine and soap respectively. Ground-nut oil has a specific gravity of 0·92 at 15° C., and its solidifying-point is 2° C.

Olive Oil

Source and Preparation.—Prepared from the fruit of the olive tree, which grows abundantly in the countries bordering the Mediterranean. The fruits have an oily flesh, surrounding a two-celled stone containing the kernel. The pulp or flesh, which contains 50 per cent of oil, is first separated from the kernels and pressed.

After expression, extraction with solvents is often employed in addition, as the oil left after expression is more valuable than the cake.

Properties.—The colour varies from water-white (colourless) to golden yellow, and the taste of the purest oil is pleasant. Its specific gravity is 0·918 and its solidifying-point 2° C. It is often adulterated with sesamé oil, cotton-seed oil, soya-bean oil, and arachis oil.

Uses.—

1. Olive oil is the king of edible oils, being used as a salad oil and for preserving sardines, &c.

2. Lower qualities are used in the arts as burning oils, lubricating oils, and soap-making oils.

Castor Oil

Source and Preparation.—Obtained from the seed of the castor-oil plant, which grows in tropical and subtropical countries. The seed contains 50 per cent of oil. Medicinal oils are expressed in the cold.

The pressed cake cannot be used for cattle food, and the oil which remains is extracted with carbon bisulphide, the extracted oil being put to industrial uses.

Properties.—It is a colourless or pale green oil,

whose specific gravity is 0·96 and its solidifying-point is −10° C. It is the heaviest and the most viscous of all the natural fatty oils. It is almost insoluble in petroleum and paraffin oils.

Uses.—

1. Used in medicine as a purgative.

2. For the preparation of transparent soaps.

3. In India it is used as a lubricant for locomotive bearings, but in this country it is too viscous for this purpose. It is used, however, for lubricating marine engines and for the manufacture of blended lubricating oils.

Fig. 6.—Measuring-flask

4. Used also as a preservative for leather belting in heavy work.

EXPERIMENT 8.—*To test the drying power of raw linseed oil.*

Smear a small sheet of glass with raw linseed oil, and set aside in an upright position for three days to dry. It will be found that the oil dries free from tackiness, and is converted into a transparent, yellow, flexible substance insoluble in water, alcohol, and to a great extent in ether.

EXPERIMENT 9. — *To find the specific gravity of castor oil.*

In the case of viscous oils, a small graduated flask should be used instead of a specific-gravity bottle. Take a clean, dry measuring-flask (100 c. c.) and find its weight when empty. Fill to the mark with castor oil and reweigh, thus finding its oil content. The water content is known from the capacity of the flask (fig. 6).
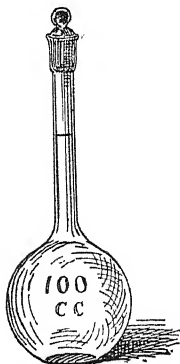
$$Specific\ gravity = \frac{oil\ content}{water\ content}.$$

Vegetable Oils

		Percentage of oil in seed or kernels.	Specific gravity.	Solidifying-point.	Uses.
Drying	Linseed Oil	35	0.930	− 20° C.	Making paint and varnish
	Hemp-seed Oil	30	0.925	− 27° C.	Making paint
	Walnut Oil	60	0.925	− 27° C.	Making artists' paints
	Soya-bean Oil	18	0.924	− 15° C.	Frying oil. Soap-making
	Poppy-seed Oil	45	0.925	− 18° C.	Artists' paints. Soap-making
Semi-drying	Cotton-seed Oil	20	0.924	+ 4° C.	Margarine. Soap-making
	Sesamé Oil	55	0.924	− 5° C.	Margarine. Soap-making
	Croton Oil	54	0.940	− 7° C.	Medicinal purposes
	Colza Oil	38	0.916	− 10° C.	Illumination. Lubrication
Non-drying	Arachis Oil	45	0.920	+ 2° C.	Edible purposes
	Hazel-nut Oil	55	0.917	− 10° C.	For lubricating watches
	Olive Oil	50 (pulp)	0.918	+ 2° C.	Edible oil. Lubrication
	Castor Oil	50	0.960	− 10° C.	Medicine. Lubrication

QUESTIONS ON CHAPTER IV

1. Why cannot linseed oil be used for illuminating or lubricating purposes?

2. What weight of oil is contained in 5 tons of each of the following seeds: Soya beans, hemp seed, walnut kernels, poppy seed, linseed?

3. How do semi-drying oils differ from true drying oils and non-drying oils?

4. Find the number of gallons in 1 ton of colza oil of specific gravity 0·916, given that 1 gall. of water weighs 10 lb.

5. When will it be more profitable to completely recover the oil from pressed meal by solvents, than to sell the cakes from the presses as cattle food?

6. Why cannot petroleum spirit be used for the extraction of castor oil?

CHAPTER V

Animal Oils

The fatty oils obtained from animals are subdivided into:

Animal Oils.	*1. Marine Animal Oils.*	*a. Fish Oils.*	*Sardine Oil.* *Herring Oil.*
		b. Liver Oils.	*Cod-liver Oil.* *Shark-liver Oil.*
		c. Blubber Oils.	*Whale Oil.* *Seal Oil.*
	2. Land Animal Oils.	*Sheep's Foot Oil.* *Horse's Foot Oil.* *Neat's Foot Oil.*	

1. MARINE ANIMAL OILS

The marine animal oils are liquids at the ordinary temperature, and are readily distinguished from other oils by their fishy taste and smell. Their specific gravities vary between 0·916 and 0·930. These oils, like the vegetable drying oils, have the power to absorb oxygen, and, when used alone, dry to a somewhat sticky skin, the fish oils drying better than the liver oils.

a. Fish Oils

These are obtained from all parts of common fish, such as the sardine, herring, salmon, &c., by boiling with water. Nowadays, by means of steam trawlers and motor-boats, the fish can be brought ashore to the rendering establishments within a day or two of being caught. As a consequence, the very dark

colour and rank smell, which were formerly the characteristics of fish oils, have given place to oils of paler colour and a much less unpleasant, though strong fishy smell.

Herring Oil

This is obtained from the several species of herring, being prepared very largely in Norway. Its specific gravity is 0·92, and, like all other fish oils, it is largely used in the leather industry.

b. Liver Oils

The bodies of fish whose livers yield oil—notably the cod fish—yield very little oil. Before steamers were introduced into the fisheries, the fishing-boats sometimes remained for a week on the fishing-grounds, and the livers which were collected were brought ashore in a more or less putrid state, the oil obtained from them being brown in colour.

Cod-liver Oil

Source.—Genuine cod-liver oil is obtained from the liver of the cod fish. Norway and Newfoundland are the great producers.

Preparation.—The fish, after being caught by hook and line or nets, are brought ashore alive. After the livers have been taken out they are washed, sorted— those stained being discarded—and placed in tin-lined vessels provided with open steam coils. Low-pressure steam is then blown through them, when the oil exudes. The crude oil is then filtered and bleached.

Properties.—The colour of the pure medicinal oil is pale yellow. The best qualities have only a slightly

fishy odour and not an unpleasant taste. The lower qualities are darker in colour. Its specific gravity is 0·924, and its solidifying-point about −5° C. Like fish oils it absorbs oxygen.

Uses.—

1. For medicinal purposes.

2. Commercial varieties are used in the leather industry by tanners and curriers.

c. Blubber Oils

The name "train oil" is often applied to all the blubber oils, although, strictly, the proper train oil is obtained only from the Greenland whale.

Whale Oil

Source and Preparation.—Whale oil is obtained from the blubber of various species of the Northern or Greenland whale. The whales are brought into the "trying" stations in Iceland, and also on the Faroe, Shetland, and Hebrides Islands. The blubber is stripped so as to leave as little flesh as possible on it. It is then cut into strips, chopped by machinery, thrown into melting-pans, and boiled with steam. Different qualities of oil are produced, the first running being the purest.

Properties.—The best quality comes off the blubber first, and is of a pale yellow colour, and has but a faint fishy smell. The lower grades become darker in colour and more objectionable. Its specific gravity is 0·92.

Uses.—

1. The pale brands are used as illuminating oil and in soap-making.

2. The lower qualities are used for leather-dressing, for tempering steel, and as a lubricant for screw-cutting machines.

Seal Oil

Source and Preparation.—Seal oil is prepared from the blubber of various species of seals by the method of rendering used for whale oil.

Properties and Uses.—The different qualities depend on the length of time taken to render, the highest quality being the first running, that obtained later being darker. Its specific gravity at 15° C. is 0·925, and it solidifies at −2° C. Seal oil has a similar composition to cod-liver oil, and possesses even less taste and smell. The finer grades are used for burning in lighthouses and also for adulterating cod-liver oil. The lower qualities are used in the leather industry and for making soft soap.

2. LAND ANIMAL OILS

The most important land animal oils are prepared from the feet of animals. The most useful oil of this class is neat's foot oil.

Neat's Foot Oil

Source.—This oil is prepared from the feet of cattle, being obtained on the large scale as a by-product in the meat-packing centres of North and South America.

Preparation.—The feet are washed, after which the hoofs are loosened in boiling water and removed by a machine. The feet are then boiled with water in jacketed pans heated by steam, the water being kept

simmering for ten hours. As the oil rises to the surface it is skimmed off, filtered, and dried by steam heat.

Properties.—It is a pale yellow limpid liquid, and has a bland taste. It has a specific gravity of 0·916 at 15° C., and it solidifies at −4° C. The high price encourages fraud, and it is largely adulterated.

Uses.—

1. It is a very valuable lubricating oil for clocks, guns, sewing-machines, and other delicate mechanisms.

2. Largely used in the leather industry, in which practically all the neat's foot oil made is used, for the production of the finer grades of leather for gloves, &c.

Animal Oils

			Specific Gravity.	Uses.
Marine Animal Oils	Fish Oils	Sardine	0·930	Tanning leather. Making soft soap.
		Herring	0·920	Leather industries. Soft soap.
	Liver Oils	Cod-liver	0·924	Medicine. Leather industries. Soap.
		Shark-liver	0·920	Leather industries. Soap-making.
	Blubber Oils	Whale	0·920	Illumination. Soap. Leather. Lubricant.
		Seal	0·925	Illumination. Soap-making. Leather.
Land Animal Oils		Sheep's Foot	0·915	Lubrication. Leather industries.
		Horse's Foot	0·916	Lubrication. Leather industries.
		Neat's Foot	0·916	Lubrication. Leather industries.

1. Name two fish oils, two liver oils, and two blubber oils.

2. Why were fish oils so objectionable formerly? State the reasons why they are not so objectionable nowadays.

3. How is medicinal cod-liver oil prepared, and what precautions are taken to ensure its purity?

4. What would be the reading on a common hydrometer, if floated in cod-liver oil?

5. Give the uses of animal oils.

6. Find, in kilograms, the weight of one hectolitre of neat's foot oil, of specific gravity 0·916.

CHAPTER VI

Solid Fats and Waxes

SOLID FATS

The solid fats are split up into the following subdivisions:

Solid Fats.

1. *Vegetable Fats.*
  - *Shea Butter.*
  - *Palm Oil.*
  - *Palm-kernel Oil.*
  - *Cacao (cocoa) Butter.*
  - *Coco-nut Oil.*

2. *Animal Fats.*
  - *Horse Fat.*
  - *Goose Fat (Grease).*
  - *Lard.*
  - *Tallow.*
  - *Butter Fat.*

1. Vegetable Fats

Vegetable fats are obtained from plants widely distributed over tropical and subtropical regions. Tropical West Africa, the East Indies, and the vast regions of tropical South and Central America yield large quantities of vegetable fats. These fats are chiefly accumulated in the seeds, though in the case of palm oil it is obtained from the fruit flesh, and this oil is quite different from the fat of the seed (palm-kernel oil). The members of this class are solid in temperate climates, some being soft buttery masses, while others are hard and wax-like.

Palm Oil

Source.—This fat is obtained from the fruit of the palm tree. The fruits are reddish-brown or black, irregular in shape, and about $1\frac{1}{2}$ in. long by 1 in. diameter.

Each fruit consists of a firm, fleshy part, surrounding the hard nut. The fleshy part of the ripe fruit yields palm oil, whilst the kernel inside the hard nut is the source of palm-kernel oil. They grow in dense clusters or bunches; a single bunch bears from 1000 to 2000 fruits and weighs about 24 lb.

Preparation.—The natives adopt exceedingly crude methods for obtaining the oil. The fruit is first converted into a pulpy mass, by burying it in a hole in the ground until it begins to decompose. The nuts (or stones) are then separated, and the pulp is placed in a pot with a small quantity of water and heated over a good fire, when the oil rises to the top and is skimmed off. The fruit contains 38·5 per cent of

pulp, 46 per cent of shells, and 15·5 per cent of kernels. The flesh contains 60 per cent of oil.

Properties.—The consistence of commercial palm oil varies from that of soft butter to that of tallow, and the colour varies from orange yellow to dark red. It has a sweetish taste and a pleasant odour resembling violets, which persists when it is made into soap. Its specific gravity is 0·92 and its melting-point 35° C.

Uses.—

1. When fresh it is used as a cooking oil by the natives.

2. Its chief uses are in the soap and candle manufactures.

3. It is also used in the tinplate industry, to preserve the surface of the heated sheet from oxidation until dipped into the bath of molten tin.

Palm-kernel Oil

Source and Preparation.—The fat known as palm-kernel oil is obtained from the kernels of the palm tree. The shells are removed from the nuts by native women and children, by cracking each one with a hammer or stone. The kernels are then shipped to Liverpool, Marseilles, and other ports. At the oil mills they are ground to a paste, and the oil is obtained either by expression or extraction with solvents. The kernels contain 50 per cent of oil.

Properties and Uses.—It is either a white or pale yellow fat. When fresh it has a pleasant smell and agreeable nutty taste. Its specific gravity is 0·91, and its melting-point 28° C. Mixed with other oils and fats it is used in soap-making.
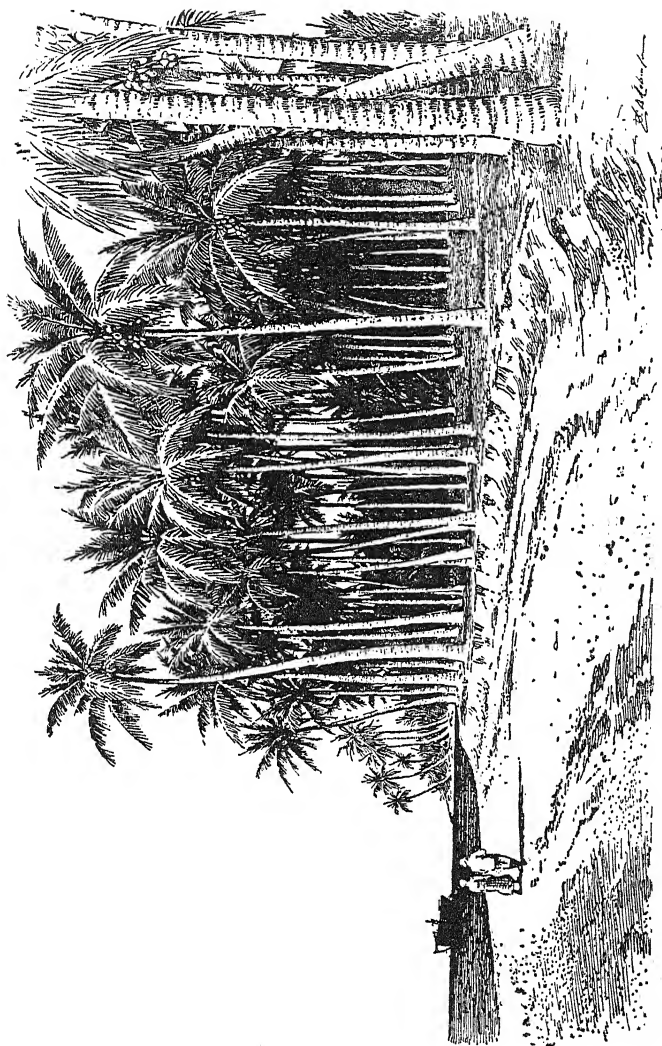
Fig. 7.—Coco-nut Palms

Coco-nut Oil

Source.—Coco-nut oil is prepared from the kernels of the coco-nut palm. The fruit is about the size of a man's head, and when ripe consists of a fibrous husk about 2 in. thick, enclosing the hard bony shell
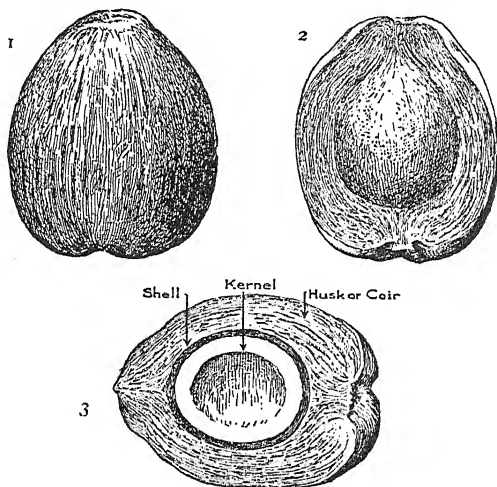
Fig. 8.--Coco-nut

1, Coco-nut: entire fruit. 2, Section of husk cut vertically through its centre showing the embedded shell of the nut. 3, Section showing husk, shell, and kernel.

of the nut. Each nut contains a fleshy part adhering to the shell, and a cavity containing a milky juice rich in oil.

Preparation. — The husk is removed, the nut cracked, and the kernels are either used fresh for the production of oil or dried. The oil can be obtained from the fresh kernels by boiling with water and skimming off the oil, or by expression, or by extrac-

tion with solvents. The fresh kernels contain 35 per cent of oil. When dried, the kernels are known as "copra". Converting into copra reduces freight, and preserves the oil of the nut. Coco-nut oil is always prepared from copra by expression. The dried kernels, which contain 60 per cent of oil, are prepared either by sun-drying or by artificial drying.

Properties.—In our climate it is a solid white fat. It has a bland taste, and, when fresh, the peculiar but not unpleasant odour of coco-nuts. It has a relative density of 0·925, and its melting-point is 25° C. It resembles palm-kernel oil very closely.

Uses.—

1. It is used in enormous quanties in the soap manufacture.

2. It is also used as a vegetable butter.

2. ANIMAL FATS

Almost every known animal is capable of yielding more or less fat by proper treatment, but for practical purposes, comparatively few are actually employed as sources of fat. The fats (butters) contained in milk have quite a different composition from that of the fats present in the adipose tissues of the body.

Lard

Source and Preparation.—Originally the name lard denoted the fat rendered from the "leaf" of the pig, that is, the fat from the kidneys and intestines. At present, however, lard denotes the fat from all parts of the animal. The original lard is still sold as "butchers' lard" and "home-rendered lard", though the quantity is insignificant.

" Bladder lard " was originally " leaf " lard rendered in small establishments, and still denotes the best quality. Keg lard contains fat from all parts of the pig. The rendering of lard in large quantities is carried out in digesters.

Properties and Uses.—Leaf lard is pure white, has an agreeable taste, and is much harder than that prepared from other parts of the animal. Its relative density is 0·935 at 15° C., and its melting-point is 27° C. The highest qualities are used in cooking and in the manufacture of margarine, the lower qualities being employed for making soap and lard oil.

Lard Oil.—This is obtained from lard by hydraulic pressure.

It is a pale yellow or colourless liquid, and is quite unsuitable for edible purposes. It is used as a high-class lubricating oil, a burning oil, and also in the silk manufacture.

Tallow

Source and Preparation.—In commerce a distinction is made between beef tallow and mutton tallow. The former is obtained from oxen, cows, and calves, the latter from sheep and goats. Tallow is prepared by rendering in digesters, the meat-packing establishments generally having fully equipped tallow-rendering appliances. For producing tallow for making margarine, the valuable kidney fat (suet) is not mixed with the fat from other parts of the animal.

Properties and Uses.—Beef tallow is nearly white, free from disagreeable odour, and almost tasteless. Mutton tallow has a more unpleasant flavour, and for this reason cannot be used for producing high-class margarine. The specific gravity of both varieties is 0·94 at 15° C. The melting-point of beef tallow is 45° C., that of mutton tallow being 48° C. Tallow is

used for making margarine, for soap-making, for candle-making, and as a lubricant.

Tallow Oil. — This is expressed from tallow by hydraulic pressure.

It is a liquid or semi-solid, depending on the temperature at which it was expressed. When mixed with mineral oils it forms a valuable lubricating oil.

Butter Fat

Source and Preparation.—Butter fat or milk fat is contained in cows' milk. The production of butter on the farm is one of the oldest domestic industries. It is, however, a domestic industry which is rapidly dying out, because the conditions essential to its success, viz. cleanliness and cooling arrangements, cannot be easily attained. The house industry is giving way to the production of butter on a larger scale, in creameries or dairies. It is prepared by churning cream obtained from milk, the butter produced being washed.

Properties and Uses.—Butter has no special colour. That made when the cows are on grass is yellow, whereas in winter, when they are stall fed, the butter is almost white. Well-made butter, from which the buttermilk has been carefully washed, will remain sweet for a considerable time without turning rancid. Ordinary butter contains about 80 per cent of fat and 16 per cent of water. Its specific gravity is 0·94 at 15° C., and its melting-point varies from 29½° C. to 34½° C. It is used for edible purposes, and also in the manufacture of some of the high-class brands of margarine.

WAXES

The waxes may be classified very simply in the following manner:

Waxes.
  1. Solid Waxes.
    Spermaceti.
    Bees-wax.
    Wool Wax.
  2. Liquid Waxes.
    Sperm Oil.
    Arctic Sperm Oils.

1. SOLID WAXES

The solid waxes have a much firmer texture than solid fats at the ordinary temperature.

Spermaceti

Source and Preparation.—Sperm wax or spermaceti occurs in the head cavities and blubber of the sperm whale and bottlenose whale. When the sperm oil from these cavities is allowed to stand, it deposits about 11 per cent of spermaceti.

Properties and Uses. — Refined spermaceti is a lustrous, white, transparent, tasteless, odourless solid. It is so brittle that it can be rubbed to powder. Its specific gravity is 0·96, and it melts at 44° C. It is used for making sperm candles and also as a cosmetic.

2. LIQUID WAXES

These resemble blubber oils somewhat, but are readily distinguished from fatty oils by their low specific gravities. The liquid waxes absorb very little oxygen from the air, and therefore do not dry.

Sperm Oil

Source.—This oil is obtained from the cavities in the head and also from the blubber of the sperm whale.

Properties and Uses.—Refined sperm oil is a pale yellow, thin oil, almost free from odour, whose specific gravity is 0·88.

Its high price invites adulteration with fatty oils and mineral oils. It is a valuable lubricant for spindles and light machinery.

Solid Fats

		Specific Gravity.	Melting-point.	Uses.
Vegetable	Shea Butter ..	0.918	25° C.	Edible fat. (Where produced.)
	Palm Oil	0.920	35° C.	Cooking fat by natives. Soap. Candles.
	Palm-kernel Oil	0.910	28° C.	Soap-making.
	Cacao Butter ..	0.970	30° C.	Edible fat. Chocolate manufacture.
	Coco-nut Oil ..	0.925	25° C.	Soap. Vegetable butter.
Animal	Horse Fat	0.919	40° C.	Edible fat. Soap-making. Leather greases.
	Goose Fat	0.920	30° C.	Emollient.
	Lard	0.935	27° C.	Cooking. Margarine. Soap. Lard oil.
	Tallow	0.940	45° C.	Margarine. Soap. Candles. Lubricant.
	Butter Fat ..	0.940	32° C.	Edible purposes. Making margarine.

Waxes

Solid	Spermaceti	0.960	44° C.	Sperm candles. Cosmetic.
	Bees-wax	0.960	63° C.	Candles. Wax polishes. Modelling.
	Wool Wax	0.940	39° C.	Ointments. Cosmetics.
Liquid	Sperm Oil	0.880	———	Lubricating oil. Burning oil.
	Arctic Sperm Oil	0.880	———	Lubricating oil. Burning oil.

1. Why are the fats such as palm oil and coco-nut oil styled oils?

2. What is copra?

3. What are the uses of palm oil and coco-nut oil?

4. How does beef tallow differ from mutton tallow?

5. What are butchers' lard, bladder lard, keg lard?

6. A piece of spermaceti whose volume is 15 c. c. floats in water. What volume is immersed?

CHAPTER VII

Group B.—Essential Oils

The essential oils are the sweet-smelling oils of plants. They are obtained either by pressure or by distilling with water the aromatic plants which yield them.

Common Essential Oils.—A few of the oils belonging to this group are: Oil of turpentine, oil of cloves, eucalyptus oil, oil of peppermint, oil of thyme oil of garlic, oil of lavender.

Composition.—A few of them, such as oil of turpentine and oil of lemon peel, are hydrocarbons (compounds of carbon and hydrogen), but the greater number contain oxygen in addition to carbon and hydrogen

Properties.—They are acrid, caustic, aromatic limpid liquids, colourless when pure, but when impure they have a yellowish colour. They mix in all proportions with fatty oils, such as linseed, colza, and whale oils, and dissolve freely in ether and alcohol from the latter solvent they are precipitated by the addition of water. They are volatile oils, their boil

ing-points being considerably above 100° C., some of them undergoing partial decomposition. They communicate a greasy stain to paper, which disappears on warming; by this means any adulteration with fatty oils can be at once detected.

Uses.—These oils are largely used for flavouring purposes under the name of essences. They are also used in medicine and for perfumery.

Oil of Turpentine

Source and Preparation.—This oil is contained in the wood, bark, leaves, and other parts of pine trees and fir trees. It is prepared from crude turpentine, which is the oily, resinous juice which exudes from cuts made in the bark of the tree. On distilling this substance, either alone or with water, oil of turpentine distils over, the residue being common resin. Oil of turps is its commercial name.

Properties.—It is a colourless, mobile liquid, having a peculiar aromatic odour. It is insoluble in water, but dissolves freely both in ether and alcohol. It is a solvent for iodine, sulphur, phosphorus, and many other substances insoluble in water, such as fatty oils and resins. Exposed to the air, it slowly absorbs oxygen and is converted into a resinous substance. Genuine oil of turps should have a specific gravity of 0·865 at 15° C. Its boiling-point is 159° C. It burns with a very sooty flame, and a sheet of glass held over the flame becomes coated with a layer of lampblack (amorphous carbon).

Uses.—

1. It is used in the preparation of oil varnishes.

2. Also used for mixing with colours; as a solvent and as an embrocation.

Fig. 9.—Gathering Crude Turpentine

EXPERIMENT 10.—*To detect the presence of a fatty oil in an essential oil.*

Allow one drop of oil of turpentine to fall on a sheet of white paper. Warm the sheet before the fire, when the grease spot disappears. Mix one drop of olive oil with half a dozen drops of oil of turps, and allow one drop of the mixture to fall on a sheet of white paper. Heat the sheet gently before the fire, and the grease spot persists.

EXPERIMENT 11.—*To find the specific gravity of oil of turps with a common hydrometer.*

Fill a tall cylindrical jar about three-quarters full of oil of turps. Float in it a common hydrometer, whose highest graduation is 1000. Read the instrument when steady. Correct the reading for temperature as follows: For each degree above or below 15° C., add or subtract the coefficient of expansion of the liquid (0·001) to or from the observed specific gravity.

QUESTIONS ON CHAPTER VII

1. How could you ascertain whether eucalyptus oil is adulterated with a fatty oil?

2. How is oil of turpentine prepared?

3. When water is added to a solution containing oil of turpentine in alcohol, the turpentine is thrown out of solution. Give the reason for this.

4. How would you prepare a sheet of smoked glass for watching a solar eclipse?

5. State the uses of the essential oils.

6. The reading of a common hydrometer floating in oil of turps is 875 at 5° C. Find its specific gravity at 15° C.

CHAPTER VIII

Group C.—Mineral Oils or Rock Oils

Classification.—The mineral oils fall into the following subdivisions:

Mineral Oils.
1. *Natural Oils.*
   - *Petroleum Spirit.*
   - *Burning Oils.*
   - *Intermediate Oils.*
   - *Lubricating Oils.*
   - *Solid Products.*
2. *Artificial Oils.*
   - *Paraffin Naphtha.*
   - *Burning Oils.*
   - *Intermediate Oils.*
   - *Lubricating Oils.*
   - *Solid Products.*

1. Natural Mineral Oils

The natural mineral oils are the crude petroleum oils, found as springs and subterranean reservoirs, often accompanied by natural gas. The name petroleum is derived from the Latin *petra* = a rock, and *oleum* = oil. The name paraffin oil is properly applied only to the shale-oil product or artificial mineral oil.

General Distribution of Petroleum. — There is scarcely any part of the globe where petroleum does not occur. The chief oil-producing countries are the United States, Southern Russia, Mexico, Burma, Persia, and Rumania.

Petroleum in Britain.—During the past few years, search for petroleum has been made in various parts

Fig. 10.—Sinking Oil Wells: diagram showing string of tools in position for drilling

Fig. 11.—Drilling Bits

WIRE ROPE

WIRE ROPE SWIVEL

JARS FROM 5 TO 6½ FT LONG

SINKER BAR FROM 15 TO 40 LONG
sometimes supplied in 2 sections

DRILLING BIT FROM 4 TO 6 FT LONG

6'

4'
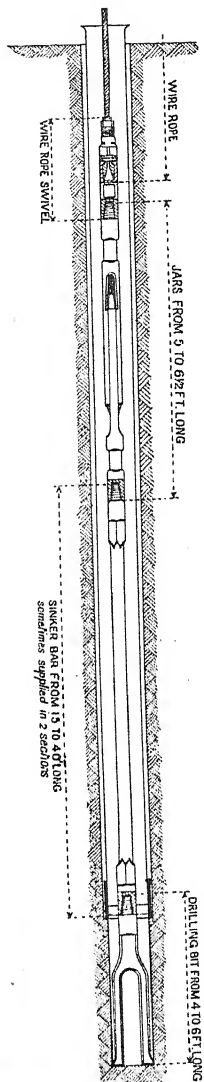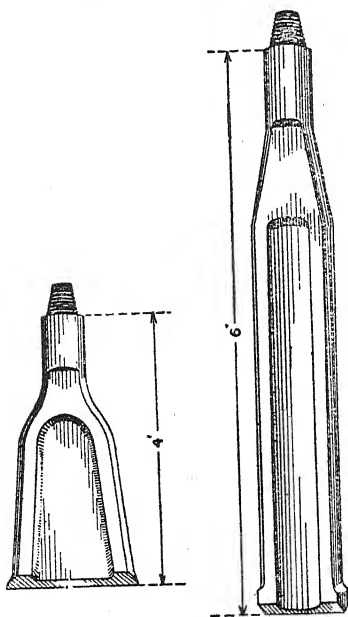
of Great Britain, but, with the exception of a well in Derbyshire, there is still little sign of any payable find. This well, at Hardstoft, has yielded approximately a ton of oil per day pending Government legislation, but it is capable of producing considerably larger quantities.

Origin of Petroleum.—The question of the origin of petroleum has attracted the attention of men of science, some adhering to the theory that it is formed from inorganic materials, while others maintain that it has been formed from animal and vegetable substances. Speaking generally, it may be said that the best authorities agree in considering the greater part of the petroleum in the earth's crust to be the result of the decomposition of the remains of marine plants and animals, and of the fat-containing parts of land vegetation.

Petroleum Wells.—The oil sometimes issues from the ground in the same way as an ordinary spring gives water. Generally, however, the oil is reached by boring or drilling through the overlying rocks to the oil-bearing strata. In most oilfields the oil-bearing rock lies at a depth of from 50 to 2000 ft. below the surface.

The diameter of the well in American oilfields is 10 in., but in Russia it is much larger, sometimes 26 in.

Pressure in Wells.—Natural gas and oil frequently issue from the wells at great pressure, more especially when first liberated. This pressure is sometimes so great that, when the oil stratum is reached, the boring tools are expelled from the bore-hole, and the oil escapes in a fountain. Such "spouting wells" have been particularly frequent in Southern Russia, and have often resulted in great waste.
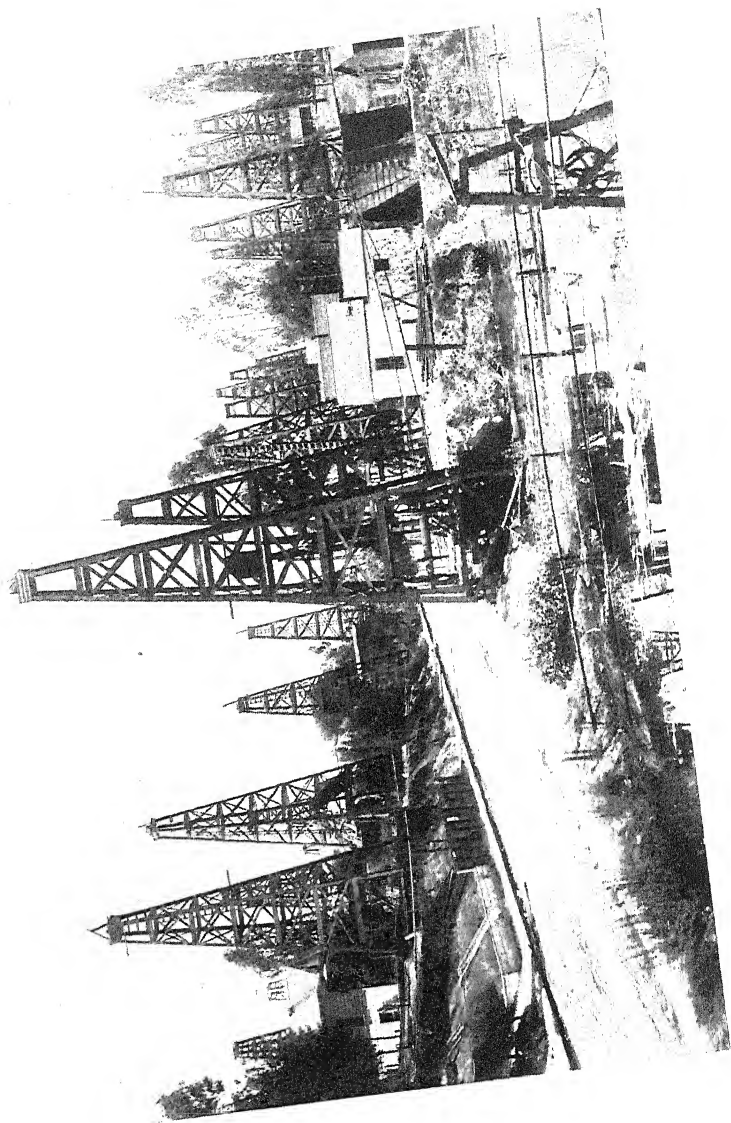
A well at Baku (S. Russia) spouted for four months an oil column from 100 to 350 ft. high, causing a loss of about 100,000,000 gallons of oil, and forming a large petroleum lake which overflowed into the Caspian Sea.

Some wells flow like a spring, while others have to be pumped. The pressure of the natural gas in some of the gas wells of Pennsylvania amounts to about 800 lb. per square inch.

Causes of Pressure.—Three theories have been brought forward to explain this great pressure:

1. That it results from the weight of the overlying strata;

2. That it is due to water pressure, the water entering the stratum at its outcrop, forming a " head ";

3. That it is due to the gradually accumulating gas having had no opportunity of escaping and being thus brought into a highly compressed condition.

Properties of Crude Petroleum

As it comes from the well it is an oily liquid, varying in physical and chemical properties in different countries, and at different depths in the same district. In composition, it may be described as a complex mixture of hydrocarbons (compounds of carbon and hydrogen).

Colour.—It is usually of a brown colour by transmitted light, but by reflected light commonly exhibits a green colour. Some varieties are, however, so dark in colour as to appear black, unless viewed in a thin layer. On the other hand, crude oil is occasionally met with of a pale yellow colour, and sometimes red and orange.

Odour.—The odour of crude oil of good quality is generally not unpleasant, but when sulphur com-

pounds are present in the oil the odour may be most offensive.

Specific Gravity.—The crude oil is nearly always lighter than water. The lowest specific gravity recorded is 0·771 in samples from Washington (U.S.A.) and Sumatra, and the highest 1·06 in a Mexican sample. The range for American oils is between 0·785 and 0·945, and for Russian (Baku) oils 0·85 to 0·9.

Volatility. — The lighter descriptions are highly inflammable and give off vapour very freely, not only at the ordinary temperature, but even when cooled below the freezing-point of water.

Specific Heat.—The average value for the crude oils is about 0·5.

Boiling-point.—The boiling-point and the amount of distillate obtained between specified temperatures differ widely. In the case of two samples of crude oil, the amount of distillate collected at various temperatures was as follows:

Percentage by Volume Distilled

Sample.	Distillation commenced at	Below 130°.	130° to 170°.	170° to 210°.	210° to 250°.	250° to 290°.	Residue.
1	82° C.	15	11	10	10·5	10·75	42·75
2	74° C.	24·5	11·5	11	9·75	7·25	36

Viscosity. — Some varieties are highly mobile, others being viscid. Increase of temperature causes a rapid decrease in the viscosity, and a rise of a few degrees will often cause a sluggish oil to flow freely.

Solubility.—Crude petroleum is insoluble in water,

but dissolves in all the fatty oils except castor oil. It also dissolves readily in alcohol, ether, carbon bisulphide, and turpentine.

Refining the Crude Oil

The refining of the crude oil has for its chief purpose the separation of the crude oil, which is a complex mixture, into the various commercial products, viz. *petroleum spirit*, *illuminating oils*, *intermediate oils*, *lubricating oils*, *and solid paraffin* (*if the crude oil yields that product*). This is accomplished by systematic distillation, the principle of which was first worked out in the Scottish shale-oil refineries, and has been adopted by the petroleum companies abroad.

The refining process is carried on, not at the wells themselves, but at large refineries, conveniently situated for export. The oil is transported to the refineries by means of long lines of pipes, through which it is forced by powerful pumps.

Petroleum Distillation

The distillation is generally divided into two operations:

1. In the first, the crude oil yields as distillates the petroleum spirit and illuminating oils, leaving in the still a residue which is run off into another still.

2. The residue from the first still is distilled again in this second still, yielding as distillates the intermediate oils (oil fuels, gas oils, &c.) and lubricating oils (which may contain solid paraffin).

Petroleum Distillation

Crude Petroleum.

Spirit or Naphtha of specific gravity 0·73 distils over below 150° C.	Illuminating Oils of specific gravity 0·8 distil over between 150° C. and 300° C. These are purified by washing with acid, alkali, and water.	Residuum of specific gravity 0·94. This goes to a second still and is distilled again, yielding

Redistilled by steam heat this yields

Gasoline   Petroleum Ether   Petrol   Naphtha   Benzine (not benzene).

{Intermediate} Oils   Lubricating} Oils   Coke (left in still).

Petroleum Stills

The stills usually employed in petroleum refineries are of the horizontal cylindrical form (fig. 13). They are 30 ft. long by 12½ ft. diameter, and are constructed of boiler plate, and arranged in lines or batteries. The vaporized oil passes through the vapour pipe to the condenser, and is thus brought again into the liquid condition.

QUESTIONS ON CHAPTER VIII

1. How has petroleum probably been formed in the earth?

2. Give the chief properties of crude petroleum.

3. What is crude petroleum?

4. What is a spouting well? State the cause of the spouting.
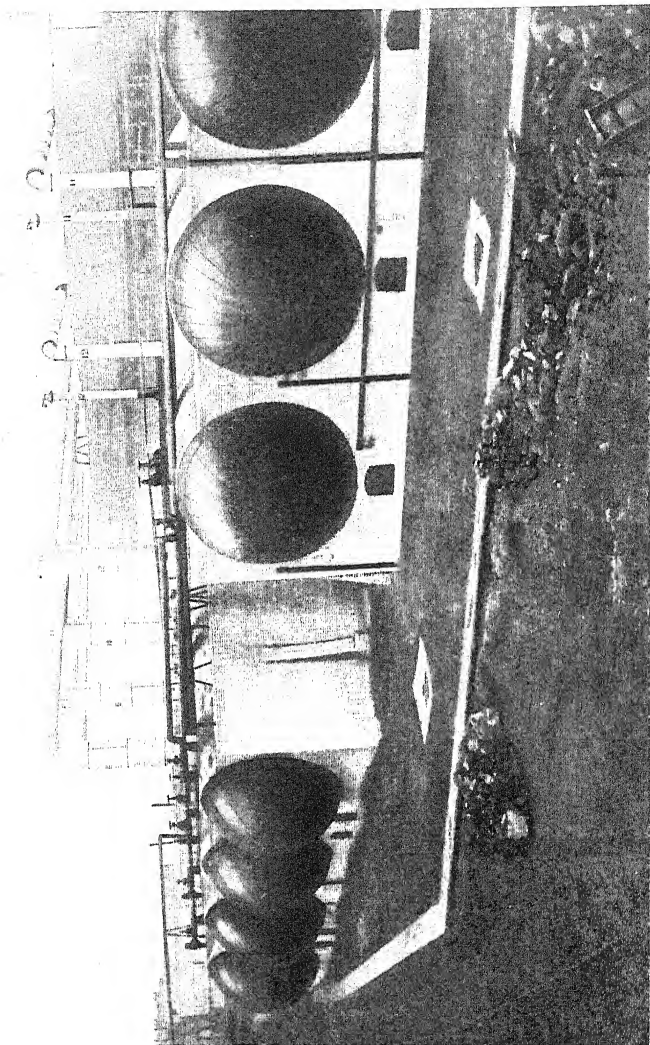
5. Describe the distillation of crude petroleum.

6. An oil well is 2000 ft. in depth and its diameter is 10 in. Find the weight of oil (in tons) which it contains when full, its specific gravity being 0·85. Assume a cubic foot of water weighs 62·5 lb.

———

CHAPTER IX

Petroleum Products

PURIFICATION OF PRODUCTS

The products obtained by distillation are not in marketable condition, but require chemical treatment to remove impurities, which give them a dark colour as well as an unpleasant odour. They are purified by treatment successively with sulphuric acid and a solution of caustic soda, followed by a washing with water. The treatment with acid, alkali, and water is assisted by agitation by a mechanical agitator, or by compressed air.

Flash-point

The "flash"-point is the lowest temperature at which an oil gives off vapours, which, when mixed with air, cause a slight explosion or flash of flame, dying out, however, at once.

Owing to the danger of fire from too volatile an oil, which may form an explosive mixture with the air, the flash-points of the various petroleum products are of extreme importance.

Ignition-point or " Fire Test "

The "ignition-point" or "burning-point" is the lowest temperature at which an oil will continue to burn, after a flame has been brought into contact with its surface for a few seconds.

The ignition-point of an oil is usually between 37° and 47° F. higher than the flash-point, that is to say, an oil which flashes at 73° F. will take fire at from 110° to 120° F.

Legal Flash-point for Lamp Oils

In consequence of the large consumption of petroleum and paraffin oils for lamps, and the danger of explosion from the use of too volatile an oil, which may form an explosive mixture with the air inside the oil reservoir, the Government insists upon a certain standard quality, which is determined by the flash-point. The lowest flash-point permitted by the Board of Trade for illuminating oils is 73° F., but it is now generally recognized that this minimum has been fixed too low. Special Acts of Parliament, known as the Petroleum Acts, apply to the storage, handling, and uses of those petroleum products which have a flash-point lower than 73° F.

Commercial Products

By distillation the crude petroleum yields a number of products, the percentage of each of which differs widely in the oils from different countries. The viscosity of these products increases with the density, but oils of the same relative density from different localities frequently differ in viscosity. The commercial products obtained from the crude oil are:

1. **Petroleum Spirit.**—This is the lightest part, and distils over at temperatures up to 150° C. On being redistilled it yields a number of products, whose specific gravities lie between 0·6 and 0·76. Petroleum spirit and its products have flash-points far below the legal standard of 73° F. They are therefore highly inflammable, and most of them evolve vapour freely even at 0° F. The following are petroleum spirit products:

    a. Gasoline.
    b. Petroleum ether.
    c. Petrol or motor spirit.
    d. Naphtha.
    e. Benzine (not benzene from coal-tar).

2. **Burning or Illuminating Oils.**—These distil over between 150° C. and 300° C. and are known in this country as petroleum oil and in America as kerosene.

They are sold under many fancy names, such as "Tea Rose", "White Rose", "Royal Daylight", "Snowflake", "Water-white Oil", &c. Their specific gravities range from 0·76 to 0·84, and their flash-points from 73° F. to 100° F.

3. **Intermediate Oils (Gas Oils).**—These are intermediate between the burning oils and the lubricating oils. They distil at temperatures above 300° C. and have specific gravities varying from 0·84 to 0·88. Their flash-points range from 100° F. to 200° F.

4. **Lubricating Oils.**—These distil over at higher temperatures than the intermediate oils, and have specific gravities ranging from 0·88 to 0·92. The lighter varieties are used for mixing with the fatty oils to form blended oils; the heavier kinds are used alone as lubricating oils. Their flash-points are far above the legal standard.

5. **Solid Products.**—Vaseline (petroleum jelly) and paraffin wax are two solid products from crude petroleum. The lubricating oil distillates, containing solid hydrocarbons, are subjected to a low temperature, when the paraffin solidifies and is separated from the oil by filter presses and hydraulic presses. The solid paraffin is then refined with animal charcoal, and thus rendered colourless, odourless, and tasteless.

Yield of Different Commercial Products

Owing to the wide variation of the crude oils, even in different oilfields in the same country, it is difficult to give more than rough approximations for the yields of the various products.

Petroleum Spirit	From 5 to 15 per cent of crude oil.
Kerosene	,, 20 to 50	,, ,,
Intermediate Oils	,, 6 to 20	,, ,,
Lubricating Oils	,, 20 to 30	,, ,,
Residue and loss	,, 10 to 58	,, ,,

Uses of Petroleum Products

Petroleum Spirit.—Petroleum spirit and its products are largely used for dry-cleaning, for extracting fatty oils from seeds, and for making spirit paint. Petrol is largely used as fuel in the internal-combustion engines of motor-cars.

Petroleum Oil or Kerosene.—Used as lamp oils for illuminating purposes and also as oil fuel.

Intermediate Oils (Gas Oils).—These are used for producing oil gas, for oil fuel for steam-raising and general heating purposes, and as fuel for heavy-oil engines.

Lubricating Oils.—Used for lubricating purposes, either mixed with fatty oils or alone.

Solid Products.—Solid paraffin is used for making candles. Vaseline is used for preparing ointments, and it also forms a good protective coating for the surface of oxidizable metal.

Coke (from stills).—Used as a fuel.

Marine Transport of Petroleum

The building of tank steamships for the marine transport of petroleum has steadily progressed, and every year sees important additions to the fleet of oil-carrying ships. Comparatively little kerosene is now landed in barrels, and lubricating oils are also largely imported in bulk.

EXPERIMENT 12.—*To find the flash-point of a mineral oil.*
The "open test" is sufficiently accurate for practical purposes. About 25 c. c. of the oil are placed in a porcelain crucible, so as to fill about three-quarters of the vessel. The crucible is embedded in a sand bath to the level of the liquid, and a thermometer is inserted into the oil. The sand bath is then heated gradually, so that the temperature may rise slowly, and from time to time a small flame is applied near the surface of the oil. The lowest temperature at which a slight explosion or flash takes place, is noted as the flash-point. It is advisable to first ascertain the approximate temperature at which a flash will take place, by means of a preliminary experiment, and then finally to determine the point more accurately. The results obtained by this method vary between 2° and 5° C.

EXPERIMENT 13.—*To determine the ignition-point of a mineral oil.*
The determination of the ignition-point is carried out in a similar manner to that in Experiment 12. A crucible about 40 mm. diameter and 40 mm. high is filled to within 5 mm. of its brim with oil, and embedded to half its height in a sand bath, a thermometer dipping into the oil. The crucible is then heated until the flash-point is reached. The burner is then lowered, and the temperature allowed to rise more slowly. After every

rise of 2° C. above the flash-point, a small flame is brought on to the surface of the oil, until it continues to burn quietly. The crucible must be protected from draught.

EXPERIMENT 14.—*To detect a fatty oil in a mineral oil.*

Take 5 c. c. of the oil to be examined, and boil it with alcoholic soda (a solution of caustic soda in alcohol) for half a minute in a large test-tube. If as little as 2 per cent of fatty oil be present, the mixture will become a gelatinous mass on cooling. If larger percentages are present the mixture will become gelatinous or even solid while hot. This experiment depends upon the fact that mineral oils are unchanged by heating with caustic soda, while fatty oils are converted into soap when thus treated.

QUESTIONS ON CHAPTER IX

1. What are the commercial products of crude petroleum?

2. Give the uses of the different petroleum products.

3. What is petrol?

4. What do you understand by the flash-point and the ignition-point of an oil?

5. How would you detect the presence of a fatty oil in a sample of petroleum?

6. A mineral oil consists of 15 per cent (by volume) of light oil of specific gravity 0·7, 55 per cent of medium oil of specific gravity 0·84, and 30 per cent of heavy oil of relative density 0·92. Find the relative density of the oil.

CHAPTER X

2. Artificial Mineral Oils

The artificial mineral oils are produced by the destructive distillation of minerals, such as oil shale, coal, lignite, and peat.
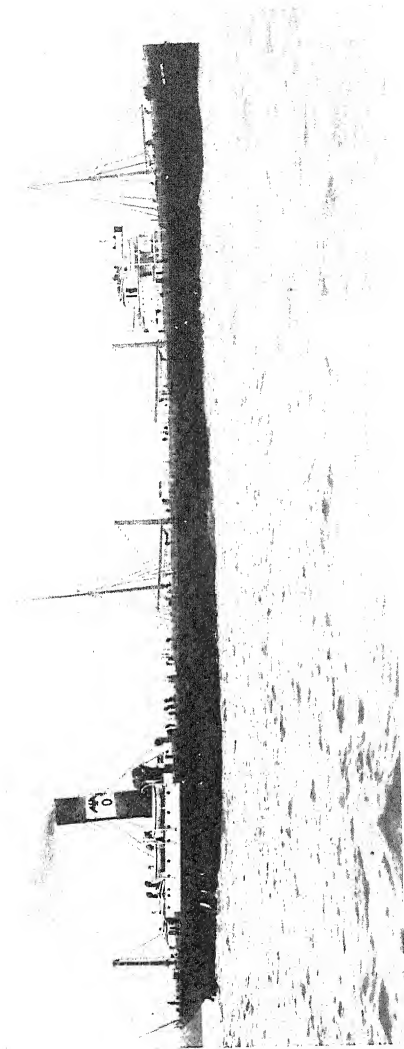
Fig. 15.—15,500-ton Oil Tanker S.S. *San Gregorio*
(Eagle Oil Transport Company Ltd.)

Destructive Distillation

This term sounds highly technical, but it simply means heating a solid strongly in a vessel or retort which is completely closed, except for one comparatively narrow exit through which the vapours pass. One of the most familiar examples of destructive distillation is the production of coal gas from coal.

Oil Shales

The distillation of oil from what are known as oil shales has been an established industry in Scotland for considerably more than half a century. This mineral is usually almost black or dark-brown in colour when freshly fractured, and is tough rather than brittle.

In a good Scottish shale from 25 to 35 per cent consists of volatile matter, but only some 2 or 3 per cent of this can be extracted by treatment with carbon bisulphide, which corresponds to between 4 and 5 gallons of oil per ton of shale.

The oil does not exist as such in the shale, but is produced by heat from the carbonaceous matter present in the mineral.

Source of Oil in Oil Shales

What we now know as an oil shale, has been at one time impregnated with petroleum or liquid hydrocarbons of some kind. This oil has been retained and fixed, so that now only a small percentage of oil can be extracted by mechanical means, and the shale has to be subjected to destructive distillation to obtain oil from it. An oil-bearing shale may, therefore, be considered as the relics of a former oilfield.

Oil Shales in Britain

The Scottish shale-fields are confined to a narrow strip of country between Edinburgh and Glasgow and on the Firth of Forth in the neighbourhood of Edinburgh. The average yield of oil from these shales at the present time is about 23 gall. per ton.

DUNDEE

FIRTH OF TAY

PERTH

NORTH

SEA

FIRTH OF FORTH

STIRLING

BURNTISLAND

GRANGEMOUTH

LINLITHGOW

LEITH

EDINBURGH

BATHGATE

WEST CALDER

GLASGOW

BERWICK
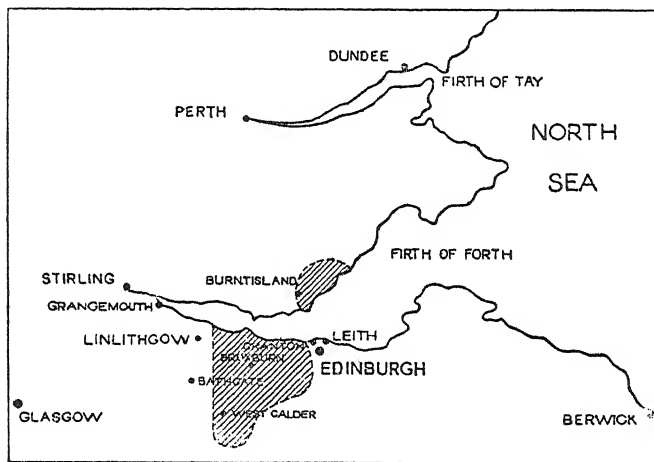
Fig. 16.—Sketch Map of the Scottish Oil-fields

Valuable oil shales have also been discovered in Dorsetshire, where at least one seam yields 40 gall. of oil per ton of shale. Quite recently, also, the presence of seams has been proved in Norfolk. The oil-shale resources of this country are by no means fully developed, perhaps not even fully recognized

Cannel Coal

This is a coal that burns with a bright flame like a candle, hence the name. It has a high percentage

of ash, seldom below 10 per cent and often as high as 30 per cent. Cannel coal yields by destructive distillation about 30 gall. per ton, of oils of a tarry type.

Lignite or Brown Coal

Lignite, whose presence has been known in this country for hundreds of years, is completely overshadowed by coal. It contains from 20 to 60 per cent of moisture, and this is a great disadvantage in the production of oils by destructive distillation. Lignite yields from 30 to 35 gall. of crude oil per ton.

The lignite deposits of other countries have proved to be valuable, and are worked on a large scale, while in this country, which depends almost entirely upon imported oils, promising lignite deposits are known but are entirely neglected.

Peat

It has been proved frequently that if peat be dried sufficiently and retorted, a fair yield of oils can be obtained. There are two great difficulties in the way of starting the production of oil from peat:

1. The cheap handling of the raw material on a large scale.

2. The effective drying of it.

Peat oils were utilized in Germany long before the War, the following products being marketed: Light oils for illuminating purposes and the manufacture of oil gas, heavy oils for lubricating purposes, wax, and asphalt.

Production of Shale Oil

The distillation of oil shales yields gas and oil, and ammonium sulphate as a by-product. The best yield of oil is obtained by distilling the shales at a comparatively low temperature.

At the present time about three million tons of shale are treated every year in Scotland, yielding about 70,000,000 gall. of crude oil. Of this, 5,000,000 gall. are motor spirit, 20,000,000 gall. are paraffin oil, 10,000,000 gall. are lubricating oil, and 25,000 tons are paraffin wax. In addition, 50,000 tons of sulphate of ammonia are produced.

Reason for Low-temperature Distillation

When a mineral oil is heated for a time it begins to boil and then passes off as vapour. If this vapour be further heated, by passing it through an iron tube heated to bright redness, "cracking" (splitting up) of the vapour takes place, and it will be split up into a permanent gas. The reason, then, why shale should be distilled at as low a temperature as possible is to obtain as much oil and as little gas as possible. On the other hand, the nitrogen in the shale, which is the source of the ammonia, is not liberated until the mineral has been subjected to almost a white heat. The shale should therefore be distilled at a low temperature to obtain the maximum yield of oil with as little gas as possible, and it should be subjected to a very high temperature to obtain the maximum yield of ammonium sulphate. The retorts are designed to attain both these objects.

Retorting the Shale

The retorts employed for distilling the shale are very similar to the vertical retorts used in modern gasworks. The charge, which enters at the top, is heated to a temperature of 480° C. in the upper iron part of the retort, where it is deprived of its gas and oil. It then passes into the more highly heated fire-brick chamber below. Here it is subjected to a temperature of over 800° C. and also to the action of

A, Small trucks, bringing shale from mine.

B, Openings, with lids, through which the shale enters the retort hopper.

C, Steel hoppers containing several hours' supply of shale, which works downwards into the retort as the spent shale is discharged at the bottom.

D, D', Steel main through which the oil and other vapours are drawn off from the retort.

E, Cast-iron retort in which oil vapours are produced from the shale at gentle heat.

F, F', Fire-brick retort in which steam reacts with carbon and nitrogen of shale at higher temperatures.

G, G', Spaces in which gas is burnt to heat retort.

H, H', Gas mains connected to combustion spaces, and supplying gas for the heating of the retort.

I, Steam main, supplying steam to bottom of retort.

J, J', Discharge gear, which maintains a constant stream of spent shale from bottom of retort.

K, Double hopper closed by bell and cone to hold spent shale as discharged until it is convenient to remove it.

L, Small steel truck for removal of spent shale.

M, M', Gangways giving access to all external parts of retort.

N, N', Steel-braced brickwork supporting and enclosing the retorts.

O, Flues from combustion spaces.

Shale moves downwards through retort, becoming hotter, while vapours move upwards, becoming cooler.

Fig. 17.—Sectional Drawing of Scottish Shale Retort (Pumpherston type)

steam, in order to convert as much nitrogen as possible into ammonia.

The upper iron part of the retort is about 11 ft. long by 2 ft. diameter, enlarging towards the bottom. The lower portion is of firebrick, about 20 ft. long by 3 ft. diameter at the bottom. The gas produced is used for heating the retorts by means of flues. The gases evolved at the top are cooled and scrubbed to remove the volatile materials. The ash, which amounts to nearly 70 per cent, is a waste product.

Crude Shale Oil

Crude shale oil is almost identical in character with crude petroleum oil. It is of a dark brownish-green colour, and has a specific gravity varying from 0·85 to 0·96. For converting the crude oil into marketable products it must be refined and purified.

Refining and Purifying

The methods employed for refining and purifying the products are almost identical with those used for crude petroleum. The fundamental operation is the distillation of the crude oil. After distillation, the largest proportion of the solids in the residue is due to the cracking or decomposition of the oil, rather than to the presence of solid impurities. This is followed by the chemical treatment with acid and alkali and washing with water, as in the case of the petroleum products.

Similarity of Shale-oil Products and Petroleum Products

The refined products from crude shale oil can scarcely be distinguished from those obtained from crude petroleum.

Uses of Shale-oil Products

The various products are used for the following purposes:

Light Spirits and Naphtha.—Motor-engines, motor-cars, varnish-making, dry-cleaning, india-rubber solvent, turpentine substitute, extraction of fatty oils from seeds.

Burning Oils.—These are commonly known as paraffin oil and are used for lamps, lighthouses, railway-signal lamps, oil engines.

Intermediate Oils.—Fuel purposes, gas making and enriching, cleaning metals, grease-making.

Lubricating Oils.—For blending with animal and vegetable oils or for use alone.

Paraffin Wax. — Candles, night-lights, tapers, match-making, waterproofing, preservative wrappers.

Source of Danger in Oil Lamps

One of the commonest sources of danger in the use of oil lamps is that arising from the burning down of a loosely-fitting and short wick, the lower end of which is not immersed in the oil. Such a wick may smoulder within the reservoir, and occasionally fire an explosive mixture of paraffin vapour and air. This danger is easily avoided by examining the wick, and renewing it before it becomes too short.

EXPERIMENT 15.—*Cracking of a mineral oil.*
Take a small quantity (50 c. c.) of petroleum or paraffin oil, and distil it in a round-bottomed flask over a burner. A few per cent will distil off at first without much change being noticeable, but the oil in the flask is in reality all the time assuming a brown colour. This very gradually gets darker and darker, until it becomes decidedly dark brown, and when the distillation is carried further it becomes black. When the distillation is

finished, a deposit of carbon will be found at the bottom of the flask, and more or less on the sides. This carbon is produced by the cracking or splitting up of part of the oil.

Questions on Chapter X

1. Why are oil shales distilled at a comparatively low temperature, and why is coal distilled at a high temperature at the gasworks?

2. What do you understand by the "cracking" of a mineral oil?

3. State the uses of each of the products obtained from crude shale oil.

4. What are cannel coal, peat, and lignite?

5. Explain how an explosion may be caused in the oil reservoir of a paraffin lamp.

6. If 10 per cent of the volatile matter in an oil shale be converted into oil, by destructive distillation, how many gallons of crude oil, of specific gravity 0·9, will be obtained from 1 ton of the mineral?

CHAPTER XI

Technology of Oils and Fats

Synthetical Oils and Fats

The supply of natural oils and fats is practically inexhaustible, therefore their technical preparation by synthetical methods is of no practical importance.

Oil and Fat Industries

The raw materials for the oil and fat industries are furnished by the oils and fats which have been described in the preceding chapters.

The chief practical uses of these bodies are:

1. For edible purposes, including cooking and the preservation of food.
2. For burning in lamps.
3. For the paint manufacture, and in the preparation of varnishes, linoleums, &c.
4. For candle-making.
5. In the manufacture of soap.
6. Miscellaneous uses.

    a. As lubricants.
    b. In the textile industries.
    c. For currying leather.
    d. For tempering metals.
    e. As solvents for odorous substances in perfumery.
    f. For the preparation of ointments, pomades, cosmetics, &c.
    g. For numerous other uses in the arts generally.

1. Edible Oils and Fats

Oils and fats are everyday articles of diet. For example, salad oils are employed for "dressing" raw vegetables; fat is used for frying; sardines, sprats, &c., are preserved in oil; butter, lard, and suet are in common use. Waxes are not adapted for edible purposes, as they cannot be digested by either human beings or animals.

Edible Oils

Most cold-drawn vegetable oils are suitable for edible purposes. Practically every vegetable oil

which has been mentioned, with the exception of croton oil and castor oil, may be and is really so employed. Animal oils are not used, except seal oil and whale oil in cold countries.

Edible Fats

Those edible fats which are natural products, such as tallow (suet), lard, and butter, are not purified before being put on the market, as they are quite fit for consumption.

Those edible fats which are substitutes for the natural products consist of artificial mixtures of different oils and fats, and include suet substitutes, lard substitutes, and butter substitutes. The enormous strides which these three industries have made during the last few years show that the popular prejudice, which at one time prevented the expansion of the trade, has now been overcome.

Butter Substitutes

These are known in this country as margarine, and in the United States as oleomargarine. This industry owes its origin to a prize offered by the French Government, owing to the scarcity of butter in the French capital when it was besieged during the Franco-German War. Experiments were carried out in Paris in 1870 which led to the manufacture of margarine, mostly from horses' fat.

Margarine, of which there are many varieties, may consist of animal fats alone, or of vegetable oils and fats, or of a mixture of animal and vegetable oils and fats. These are churned with cows' milk, a little colouring matter, and occasionally a little butter (for the highest grades). When carefully prepared, it is a perfectly wholesome article of diet.

2. Burning Oils

In the earliest stages of the history of the human race, animal fats were used for illumination. The substitution of oils for fats marked a distinct advance. The old Roman lamps, in which vegetable oils were used, were always shallow vessels, because the low capillarity of the oil prevented it from rising up the wick to any considerable height. Up to the middle of the last century, olive oil and rape oil were the illuminating oils used throughout Europe. Amongst the Eastern nations, crude petroleum has been largely used as a burning oil from time immemorial.

The development of the mineral-oil industry has caused an enormous reduction in the amount of fatty oils used for illuminating purposes, nevertheless there is a considerable quantity still employed.

3. The Paint Manufacture, &c

Paint Oils.—Those vegetable oils which are used for applying colours to the surface of bodies, either for preservation or decoration, are known as paint oils. Only the vegetable drying oils are used, linseed oil being the best. Paints for common use are prepared with " boiled " oils.

Raw Oils.—The drying oils, such as linseed oil, &c., in their natural state, after expression and refining, are known as raw oils.

Boiled Oils.—These oils take their name from the old process of heating raw linseed oil, mixed with a small quantity of suitable metallic oxides or salts—driers—over an open fire to temperatures varying from 210° to 260° C. This process was called oil-boiling.

Linseed oil, after being heated with lead oxide, absorbs oxygen more rapidly than linseed oil not so treated. Raw linseed oil requires about three days for drying to an elastic skin, but the drying process is so much accelerated by the treatment with lead oxide over a fire that it will dry within eight hours to an elastic skin.

At present, boiled oils are produced by heating raw linseed oil with driers to a temperature of 150° C. only.

Oxidized Oils (Blown Oils).—Under this term are included all those oils which have absorbed oxygen by exposure to the atmosphere, or have been oxidized artificially by heating and blowing through them a current of air or oxygen gas. Oils so treated are known commercially as blown oils or thickened oils, and are prepared from vegetable semi-drying oils, blubber oils, and liquid waxes. They increase in density and viscosity, and approach castor oil in these respects.

Blown oils are more suitable for use as lubricants, either alone or as ingredients in lubricating mixtures. If vegetable drying oils undergo this treatment, the action proceeds more rapidly than in the case of semi-drying oils, and solidified oil can be prepared in this way.

Paints.—Paints are made by grinding powdered pigments with boiled linseed oil, until free from gritty particles. The percentage of oil in different commercial paints varies, according to the nature of the pigments, from about 10 per cent for white-lead paint, to 40 per cent for black paint.

Oil Varnishes.—These are made from boiled linseed oil by mixing it with various gum-resins, such as copal, mastic, and shellac, and diluting with oil of turpentine.

Oil-cloth.—The varnish-like film of oxidized oil,

4. Greases and Solid Lubricants

This class is prepared from a great variety of fatty oils, solid fats, mineral oils, tar oils, alkali soaps, and lime soaps. They are chiefly compositions used for the axle boxes of railway rolling - stock (trucks, carriages, &c.). These axle greases are a peculiar kind of imperfect soap, which is found to answer well. It is usually made by melting tallow and palm oil together, and then thoroughly incorporating a solution of soda crystals (washing-soda).

For cart-wheels and rough machinery, such as pumping engines in mines, coarse and dark-coloured greases are used. These are refuse oils, and by-products of various industries, and are the most dangerous lubricating materials in use, from the point of view of liability to inflammation. They should never be used in a mill or building where great damage by fire might be caused.

Cutting Lubricants

A cutting lubricant is a manufactured product, and is applied to the cutting tool and the metal which is being cut in drilling, cutting, and screwing machines.

The lubricant is made in a condensed form, and consists either of oil, cream, or paste. To prepare it for use, a small quantity is placed in a tank, and mixed with the requisite amount of water, which may be 1 of lubricant to 10 of water, by weight, in some cases, or 1 of lubricant to 100 of water in others, until the mixture has the appearance of milk. This solution is put into the tanks of the machines, and is applied to the tool and metal, whilst the latter is being cut or drilled, from a tube fitted with a tap. This lubricates the tool, preventing friction, thus effecting a saving in tools and time, and, in addition, the lubricating solution will not rust the tools or metal. Such lubricants are used in the case of heavy screw-cutting machines, for pipe and stay-

bolt threading, for automatic machines, for gear-cutting machines, for turret lathes (screwing and turning), for trepanning machines, and for drilling.

Viscosity of Lubricating Oils

The viscosity of an oil enables one to draw certain conclusions. Thus if the viscosity is low, and the oil is very mobile, the film of oil which keeps the bearings of rapidly moving machinery apart is not sufficiently coherent to keep the metal surfaces from coming into contact with one another, and therefore the friction between them is not sufficiently diminished. If, on the other hand, the viscosity of an oil be high, the resistance of the film is so great that heating occurs, due to internal friction, and the bearings become warm or even hot. That oil is best which, under given conditions of speed, pressure, and temperature, has the lowest permissible viscosity.

The viscosity of lubricating oils diminishes rapidly with increase of temperature; the decrease is, however, much greater in the case of mineral oils than in that of vegetable and animal oils. This is also one of the reasons why blends of fatty oils and mineral oils are so much employed.

Comparison of Viscosities

The efflux velocity, or rate of flow through an orifice, is a measure of the viscosity of an oil. The simplest arrangement for comparing the viscosities of different oils is to measure their rates of flow through the same orifice. This can be done easily by filling a 50-c.c. pipette to the mark on the stem, with each oil in turn, the time necessary for each to run out being noted with a stop-watch. The ratio of the

times so obtained gives the relative times for equal volumes to run out, but not for equal weights.

EXAMPLE.—

50 c. c. of A, of specific gravity 0·75 (d_1), run out in 10 sec. (t_1)
50 c. c. of B, of specific gravity 0·95 (d_2), run out in 100 sec. (t_2)
The relative times for equal volumes are $t_1 \div t_2$.
But the relative times for equal weights would be:

$$\frac{t_1}{t_2} \times \frac{d_2}{d_1} = \frac{10}{100} \times \frac{0 \cdot 95}{0 \cdot 75} = 1 : 8.$$

∴ their viscosities are as 1 to 8.

Liability to "Gum"

A good lubricating oil should neither dry on exposure nor gum, as the latter causes heating and loss of energy.

Cold Test of a Lubricating Oil

The cold test is the temperature at which the oil, on being slowly cooled, deposits solids and ceases to flow.

Loss Due to Evaporation

Good mineral oils intended for heavy machinery, cylinders, &c., rarely lose more than 1 per cent on exposure for twelve hours at 100° C., while mineral oils intended for light machinery rarely exceed a loss of 0·5 per cent on exposure for twelve hours at 60° C.

Table showing the Best Purposes to which Lubricants can be Applied

For very great pressures with slow speed	Graphite, soapstone, and other solid lubricants.
For great pressures with slow speed	Tallow, lard, palm oil, and grease.
For heavy pressures and high speed	Sperm oil, rape oil, castor oil, and medium mineral oils.
For light pressures and high speed	Sperm oil, light mineral oils, olive oil.
Ordinary machinery	Rape oil, lard oil, tallow oil, and medium mineral oils.
For steam cylinders	Lard oil, tallow oil, rape oil, and heavy mineral oils.
For clocks and watches	Hazel-nut oil, neat's foot oil, olive oil, sperm oil, and light mineral oils.

EXPERIMENT 20.—*To test the relative tendencies of linseed oil (raw), cotton-seed oil, and olive oil to "gum".*

Place six drops of each oil on a surface inclined at 10° to the horizontal. Leave them for a day or two, noting each day the distance which each oil has run down. Note also the time until each oil ceases running, owing to increased viscosity.

QUESTIONS ON CHAPTER XII

1. Into what classes may lubricants be placed?

2. What are the disadvantages of mobile oils and viscous oils when used as lubricants?

3. What are cutting lubricants used for?

4. Name the oils best suited for lubricating clocks, steam-engine cylinders, spindles, ordinary machinery.

5. For what purposes are the following mineral oils best adapted: Light oils, medium oils, heavy oils?

6. 50 c. c. of an oil A run out of a vessel in 8 sec., and the same volume of an oil B runs out in 120 sec. Taking their densities as 0·918 and 0·96 respectively, compare their efflux velocities for equal weights.

FUELS

CHAPTER XIII

Combustion

SOURCES OF POWER

The bulk of the energy available at the present time, for all the varied objects of human enterprise, is derived from the combustion of fuel. The nineteenth century will always be remembered as the period in which men found out what wonderful things could be done with the help of steam. The steam, however, is only an intermediate agent; the real source of power is the fuel employed to produce the steam. A ton of coal, therefore, may be regarded as a store of energy, and the steam-engine is simply a contrivance for converting the chemical energy of the coal into mechanical work. It is true that the steam-engine has been displaced to a considerable extent by oil- and gas-engines, but in these also, although the nature of the fuel and the manner of burning it are different, it is combustion from which the power comes. Electricity also, to a certain extent, has taken the place of the steam-engine in our factories and on our railways,

but here again the combustion of coal takes place at a power-station, and the electricity generated there is distributed to the factories and railways. Combustion, then, is at the root of the remarkable engineering and industrial developments which the last hundred years have witnessed, not excluding motors, aeroplanes, and electricity.

What a Fuel is.—The term fuel embraces all substances capable of being burnt in air for the production of heat.

Essentials of a Fuel

1. It should ignite fairly easily, that is, its ignition-point should not be too high.

The ignition-point of a fuel generally depends on the proportion of hydrogen present: the larger the amount of hydrogen, the lower the ignition-point, and vice versa.

2. It should burn freely, in some cases with flame, and in other cases without flame.

Whether a fuel burns slowly or quickly depends on the draught, that is, the rapidity with which air is supplied to the fuel. For flame to be formed, a solid fuel must give off a large quantity of hydrocarbon gases.

3. It should possess as high a calorific (heating) value as possible.

The heating value of a fuel depends on the elements present in it which are capable of undergoing oxidation, with the production of heat. For all practical purposes, only two elements need be considered—carbon and hydrogen. In most fuels, however, a certain proportion of oxygen is always present, so that the hydrogen and possibly the carbon, to some extent, are already in combination with oxygen. It follows, therefore, that oxygen-containing fuels become proportionately poorer fuels as the percentage of oxygen present increases.

Combustion

All natural fuel is carbonaceous, that is, it consists mainly of carbon or of compounds of carbon and hydrogen. In the process of burning, the carbon and hydrogen of the fuel unite with the oxygen of the air, and yield respectively carbon dioxide and water, and these final products of combustion remain the same whether the original fuel is solid, liquid, or gaseous. This chemical change, which takes place during combustion, develops heat. Such a process is termed "rapid combustion", but similar changes may take place at a much slower rate, though the heat produced per unit weight of fuel is the same; yet, owing to the slowness of its production and its dissipation, it is not apparent. Such a process is called "slow combustion".

Production of Flame

Flame is produced by the combustion of gases and vapours which, in the case of solid fuels, are volatilized by heat from the fuel.

Ignition-point

For combustion to be started, a definite temperature must be reached, and, for the fuel to continue burning, this temperature at least must be maintained. Every combustible substance has its own ignition-point, but many circumstances influence the ease with which combustion may be started, mass and fineness of division being the most important.

Whilst a small quantity of coal in a finely-divided condition will ignite at a comparatively low temperature, a lump of the

same coal will require considerable heating up before it takes fire.   This is due to the smaller surface exposed to the air, in proportion to the mass, which carries away the heat.

The ignition-points of fuel oils have become a matter of great importance in connection with the Diesel oil-engine.

The following are the approximate ignition-points for various coals:

> *Highly bituminous gas coal*   *370° C.*
> *Ordinary bituminous coal*   *425° C.*
> *Welsh steam coal ...   ...   470° C.*
> *Anthracite ...   .   500° C.*

Calorific Value

The calorific value or thermal value of solid and liquid fuels is measured by the number of thermal units or calories produced during the combustion of unit mass of the fuel.   For scientific purposes, in this country, the Centigrade system forms the basis, but most practical men prefer the system based on the Fahrenheit thermometer scale, the results being expressed in British Thermal Units (B.Th.U.).

The thermal value of a gas is generally measured by the number of heat units produced by the combustion of 1 c. ft. of the gas.   From the specific gravity of the gas the heating value per pound can then be calculated.   When the calorific powers of solid, liquid, and gaseous fuels are to be compared, the gas should be taken by weight, in order to have the data in comparable form.

Thermal Units

1. The **calorie** represents the quantity of heat necessary to raise the temperature of unit mass of water through 1° on the Centigrade scale.

The **small calorie** (gramme-degree-Centigrade unit) corresponds to 1 gm. of water (unit mass).

The large calorie (kilogram-degree-Centigrade unit) corresponds to 1 Kgm. of water (unit mass).

1 small calorie = ·001 large calorie.
1 large calorie = 1000 small calories.

2. The **British Thermal Unit** is the amount of heat required to raise the temperature of 1 lb. of water through 1° on the Fahrenheit scale.

1 B.Th.U. = 252 small calories = 0·252 large calorie.
1 large calorie = 3·968 B.Th.U.

3. A third unit of heat—**the pound-degree-Centigrade unit**—is commonly used in this country, this being the amount of heat required to raise the temp\`rature of 1 lb. of water through 1° on the Centigrade scale.

This unit is generally employed in stating the calorific values of solid and liquid fuels, and is what is generally understood by "calorie" in this country. It is related to the B.Th.U. in the same way as Centigrade and Fahrenheit thermometer degrees are related to one another.

Calories (gramme-degree-Centigrade units) per gramme of fuel, multiplied by $\frac{9}{5}$ give the calorific value in B.Th.U. (pound-degree-Fahrenheit units) per pound of fuel.

Example.—
1 gm. of coal burnt in a calorimeter raised the temperature of 3000 gm. of water through 2·75° C.
Its calorific value is therefore 3000 gm. × 2·75° C. = 8250 calories per gramme.
Obviously 1 lb. of this coal would have raised 3000 lb. of water through 2·75° C. or 2·75° × 1·8 = 4·95° F.
Now 3000 lb. × 2·75° C. = 8250 lb.-degree-Centigrade units and 3000 lb. × 4·95° F. = 14,850 B.Th.U.

Its calorific value is therefore 8250 calories (14,850 B.Th.U.).

The calorific values of all solid and liquid fuels referred to hereafter will have this ratio between calories and B.Th.U.

Questions on Chapter XIII

1. What is a fuel?   Give three examples of fuels.

2. What are the requisites of a fuel?

3. Name the heat-giving elements in fuels.   When oxygen is present, what effect has it on the calorific value?

4. What do you understand by the ignition-point of a fuel?   Which element influences the ignition-point?

5. What are the products of combustion of solid, liquid, and gaseous fuels?

6. If the calorific value of a fuel is 10,000 calories per gramme, find its thermal value in B.Th.U. per pound.

CHAPTER XIV

Calorific Values

Gross and Net Calorific Values

When a fuel containing hydrogen is burnt, water is produced in the form of vapour, and if this water vapour be condensed it gives up its latent heat, together with the heat liberated by the water, in cooling from its condensation-point (100° C.) to some lower temperature.   The **gross calorific value** of a fuel is therefore the theoretical heating value of the fuel, plus the latent heat of steam, plus the heat liberated by the water on cooling from 100° C.

In many cases, however, this heat stored up in the water vapour, produced from hydrogen during its combustion, is not

available. Thus it plays no part in raising the flame temperature of burning gases, or in developing energy in a gas-engine, because flue gases and exhaust gases are seldom cooled to anything approaching 100° C., and they must therefore carry away the latent heat units. In such cases it should be eliminated, and the value after this deduction is termed the **net calorific value**. The latent heat of steam = 536·5 calories or 966 B.Th.U. In general, the deduction is taken as 600 calories, made up of 536·5 calories for latent heat + 63·5 calories for cooling of water below 100° C.

Calculation of Calorific Values

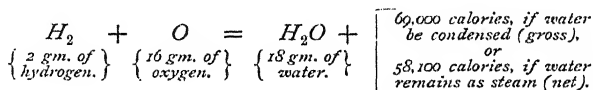**Combustion of Carbon.**—When carbon is burnt in oxygen with the formation of carbon dioxide, the weights of the materials taking part in the reaction, and the amount of heat produced, may be expressed by the thermo-chemical equation

$$C \quad + \quad O_2 \quad = \quad CO_2 \quad + \quad 97{,}200 \; calories.$$

$$\left\{ \begin{array}{c} 12 \, gm. \, of \\ carbon. \end{array} \right\} \quad \left\{ \begin{array}{c} 32 \, gm. \, of \\ oxygen. \end{array} \right\} \quad \left\{ \begin{array}{c} 44 \, gm. \, of \\ carbon \\ dioxide. \end{array} \right\}$$
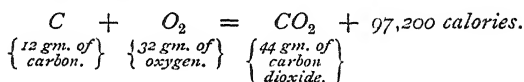
It follows that 1 gm. of carbon gives, when burnt, 8100 calories (14,580 B.Th.U.).

Combustion of Hydrogen.—When hydrogen burns with the formation of water we have

$$H_2 \quad + \quad O \quad = \quad H_2O \; + \left[\begin{array}{c} 69{,}000 \; calories, \; if \; water \\ be \; condensed \; (gross). \\ or \\ 58{,}100 \; calories, \; if \; water \\ remains \; as \; steam \; (net). \end{array} \right.$$

$$\left\{ \begin{array}{c} 2 \, gm. \, of \\ hydrogen. \end{array} \right\} \quad \left\{ \begin{array}{c} 16 \, gm. \, of \\ oxygen. \end{array} \right\} \quad \left\{ \begin{array}{c} 18 \, gm. \, of \\ water. \end{array} \right\}$$

Hence it follows that 1 gm. of hydrogen produces, when burnt, 34,500 calories (62,100 B.Th.U.), if the steam produced be condensed to water.

If the steam remain as steam, 1 gm. of hydrogen gives 29,050 calories (52,290 B.Th.U.).

1. **Fuels containing only Carbon and Hydrogen.**—The calculated calorific value (gross) of any fuel

containing only carbon and hydrogen will be found thus,

$$\left.\begin{array}{c}\textit{Calories per}\\ \textit{gramme}\\ \textit{(gross)}\end{array}\right\} = \frac{(carbon\ \% \times 8100) + (hydrogen\ \% \times 34,500)}{100}.$$

2. **Fuels containing Carbon, Hydrogen, and Oxygen.**—When a fuel contains oxygen, a smaller quantity of this gas will be required for its combustion, and the heat produced will be proportionately less. It is customary to assume that any oxygen present is already wholly in combination with hydrogen. Since 8 parts by weight of oxygen combine with 1 part by weight of hydrogen, it is usual to deduct from the total hydrogen an amount equal to $\frac{1}{8}$ of the oxygen present, the available surplus of hydrogen for combustion being equal to

$$\textit{Total hydrogen}\ \% - \frac{\textit{oxygen}\ \%}{8}.$$

In no substance used as a fuel, is the amount of oxygen present more than sufficient to unite with the hydrogen present.

The formula now becomes

$$\left.\begin{array}{c}\textit{Calories}\\ \textit{per}\\ \textit{gramme}\\ \textit{(gross)}\end{array}\right\} = \frac{(carbon\ \% \times 8100) + \left\{\left(hydrogen\ \% - \dfrac{oxygen\ \%}{8}\right)34,500\right\}}{100}.$$

3. **Fuels containing Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur.**—A fixed deduction of 1 per cent is made for the nitrogen present in the fuel, this being a fair average value for it, though rather low for English coal.

Therefore oxygen + nitrogen — 1 represents the oxygen.

1 gm. of sulphur when burnt produces 2220 cal-

ories. In the complete form, such as may be applied to coal, the following extended formula is employed:

$$\left. \begin{array}{c} \textit{Calories} \\ \textit{per} \\ \textit{gramme} \\ \textit{(gross)} \end{array} \right\} = $$

$$\frac{(C\% \times 8100) + \left\{ \left(H\% - \frac{O\% + N\% - 1}{8} \right) 34,500 \right\} + (S\% \times 2220)}{100}.$$

If we introduce a correction for the heat required to evaporate moisture present in the coal, the round number 600 is taken as the amount of heat required to heat the moisture up to 100° C. and then vaporize it. The formula then becomes

$$\left. \begin{array}{c} \textit{Calories} \\ \textit{per} \\ \textit{gramme} \\ \textit{(gross)} \end{array} \right\} = $$

$$\frac{(C\% \times 8100) + \left\{ \left(H\% - \frac{O\% + N\% - 1}{8} \right) 34,500 \right\} + (S\% \times 2220) - (H_2O\% \times 600)}{100}.$$

Evaporative Values

It is a common practice to state the calorific value of a fuel in terms of its power to evaporate water from the temperature of 100° C. (212° F.) into steam at the same temperature.

$$\textit{Evaporative value of a fuel} = \frac{\textit{calorific value in calories or B.Th.U.}}{\textit{latent heat of steam}}.$$

If the calorific value be given in calories per gramme, the denominator will be 536·5, but if expressed in B.Th.U. the denominator will be 966.

Questions on Chapter XIV

1. What do you understand by gross and net calorific values?

2. The composition of an oil fuel is: carbon 88 per cent,

hydrogen 12 per cent. Calculate its gross calorific value.

3. The approximate composition of absolute alcohol is: carbon 52 per cent, hydrogen 13 per cent, oxygen 35 per cent. Find its thermal value (gross).

4. A sample of coal has the following composition: carbon 80 per cent, hydrogen 5 per cent, oxygen 10 per cent, nitrogen 1 per cent, sulphur 1 per cent, ash 2 per cent, moisture 1 per cent. Find its calorific value (gross).

5. If the composition of a liquid fuel is, carbon 80 per cent, hydrogen 20 per cent, find its net thermal value.

6. How many pounds of water at 100° C. can be converted into steam at 100° C. by the heat produced by the combustion of 10 lb. of coal whose thermal value is 8400 calories?

CHAPTER XV
Coal and Other Solid Fuels

Classification of Fuels

Fuels may be divided into the following classes:

A. Solid Fuels.
B. Liquid Fuels.
C. Gaseous Fuels.

A. Solid Fuels

The solid fuels are naturally-occurring substances, although for special purposes they are carbonized. The chief solid fuels are:

1. *Wood and wood charcoal.*
2. *Peat, peat charcoal, and peat briquettes.*
3. *Lignite.*
4. *Coal, coke (including coalite), and briquetted fuels.*

Wood

Wood was one of the earliest fuels, but it cannot be seriously reckoned as a fuel at the present time.   A deal of wood is burned in those countries where forests are abundant, but it is scarcely used at all for manufacturing and industrial purposes.

The average composition of dry wood is:

> *Carbon*   *50 per cent.*
> *Hydrogen*   *6   ,,*
> *Oxygen and Nitrogen 44   ,,*

The thermal value of dry wood is 4700 calories (8460 B.Th.U.).

Wood Charcoal

At one time the production of charcoal was carried out by the partial combustion of wood in heaps, which
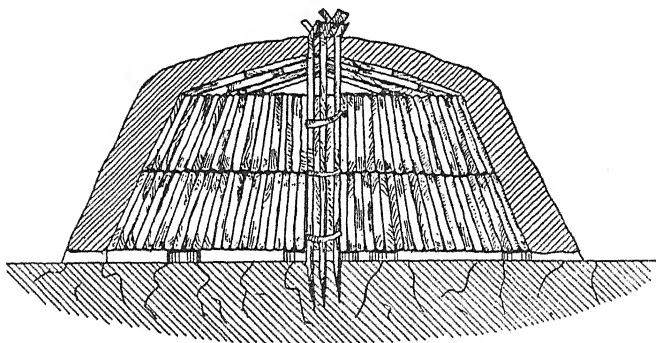

Fig. 19.—Preparation of Wood Charcoal (old method)

were covered with turf to prevent free access of air. At the present time, it is produced by the destructive distillation of wood in closed retorts, a number of

valuable oils being produced at the same time, the residue in the retorts retaining the shape and structure of the original wood, and consisting almost entirely of carbon.

Charcoal was formerly a metallurgical fuel of great importance in iron-smelting, but the introduction of coke for that purpose displaced charcoal completely from its position of importance

It has a high calorific value, viz. 8000 calories, which corresponds to 14,400 B.Th.U.

Peat

The amount of energy stored up in the peat bogs of the world is simply enormous. These bogs cover one million acres in Ireland alone, and about one hundred million acres in Russia, and it has been estimated that an acre of bog having a depth of 8 ft. would yield about 1250 tons of dried peat.

Here, then, is a huge store of fuel, which, unlike wood, cannot be used for any other purpose than burning, but owing to the situation of the bogs in sparsely populated districts, and the difficulties in drying, it is scarcely ever used, except in the immediate neighbourhood of the bogs.

By modern methods it gives every promise of producing a useful fuel, cheap power-gas, and valuable by-products. By utilizing the gas in gas-engines, for generating electric energy, and distributing the energy so generated, these out-lying peat-producing districts are likely to play an important part in the future.

Composition.—A well-drained peat bog yields peat containing from 80 to 90 per cent of water, in other words, for every ton of peat substance, 7 tons of water are present.

The average composition of peat, with water and ash eliminated, is:

<div style="text-align:center">

Carbon 57 *per cent.*
Hydrogen 6 ,,
Oxygen 35 ,,
Nitrogen 2 ,,

</div>

It seldom contains less than 3 per cent of ash, but it is not uncommon for over 10 per cent to be present.

Calorific Value.—The thermal value (average) for dry peat is about 5500 calories (9900 B.Th.U.).

Lignite

Lignite belongs to a different and more recent geological period than coal proper. It is an important fuel in India, the Colonies, and most European countries. As mined, it usually contains from 20 to 60 per cent of moisture. The ash varies over a wide range, the amount being frequently so great as to prevent it from being used except in gas-producers, or by distillation for tar oils, &c.

The amount of moisture and ash generally present make lignite an inferior fuel. Some Continental electric-light stations are run on it, and it is also used on the Italian railways.

Its thermal value varies widely, but an approximate average is about 6000 calories (10,800 B.Th.U.).

Coal

Origin.—The forests of the distant past are now no more, but we find their remains below the surface of the earth. Since the vegetation of these far-off ages died, or was submerged, the material of which it

consisted has undergone a series of chemical changes, and we dig it up to-day as peat, lignite, and coal.

Woody matter is composed of carbon, hydrogen, oxygen, and nitrogen. In the course of ages the woody matter from the fallen forests and jungles of the past has lost the greater part of its oxygen, some of its hydrogen, and some nitrogen, and has been converted more or less completely into carbon. These changes have not proceeded so far in peat as in lignite, nor in lignite as in coal.

The following table gives approximately the percentage of carbon in dry wood, &c.:

Dry wood	*50 per cent.*
Peat	*60* ,,
Lignite	*70* ,,
Cannel coal	*85* ,,
Newcastle coal	*88* ,,
Anthracite	*95* ,,

Composition. — Coal contains carbon, hydrogen, oxygen, nitrogen, sulphur, ash, and moisture.

The following table gives the approximate composition of four samples of English coking coal.

Source.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Moisture.	Total.
Durham ..	83.0	6.5	7.5	1.0	0.6	0.4	1.0	100
South Wales	83.6	4.7	4.1	0.9	1.4	4.4	0.9	100
Derbyshire ..	79.1	4.5	10.1	1.3	0.9	2.5	1.6	100
Lancashire ..	77.1	4.9	9.0	1.1	1.2	4.8	1.9	100

Oxygen (combined) in Coal.—Oxygen in coal is almost as detrimental in reducing the calorific value as ash. For example, if two samples of coal each contain the same percentage of carbon, but one contains high oxygen and low ash, while the other contains low oxygen and high ash, then the first sample will have nearly the same thermal value as the second.

Nitrogen in Coal.—It is unusual to find less than 1 per cent of nitrogen in the coal of this country, or more than 2·5 per cent, and the average is about 1·4 per cent. The nitrogen in coal is the source from which practically all the ammonia salts of commerce are derived.

Sulphur.—This element is present to about the same extent as nitrogen, viz. 0·5 to 2·5 per cent. The presence of sulphur is a matter of great importance in metallurgical fuels, as it may pass into the metal.

Phosphorus and Arsenic.—These elements occur in coal in small quantities. They are of no importance where the fuel is used for power purposes, but phosphorus in particular is very objectionable if the fuel is used in the metallurgy of iron, and both are so if the fuel is used in the metallurgy of copper.

Ash.—Ash is the incombustible matter in coal, being derived partly from that which was present in the original vegetable substance, and partly from material carried by water amongst the decaying vegetable matter, and it may also be partly due to shale.

Ash is inert material in coal and is quite valueless, and in addition it lowers the value of the coal, by choking the air passages through the grate, and frequent cleaning of the fire is necessary. It also causes deposits in tubes and flues, and if it is of a fusible character it is especially troublesome through the formation of clinkers.

The ash of coal is seldom below 1 per cent; up to 5 per cent is quite common, and sometimes it amounts to 10 or 12 per cent.

Moisture.—Ordinary coal contains from 1 to 4 per cent of moisture after air-drying.

Gases in Coal (uncombined).—In addition to the solid constituents, coal contains occluded gases, that

is gases filling the pores. This gas consists chiefly of methane or marsh gas (fire-damp). The evolution of such a highly inflammable gas as methane renders the seams in which it occurs "fiery" and extremely dangerous.

EXPERIMENT 21.—*To carbonize wood.*

Place a piece of dry wood in a hard-glass test-tube. Close the mouth of the tube roughly with asbestos, and fix horizontally in the clamp of a retort stand. Heat the tube, gently at first, then strongly for about five minutes. Allow to cool and take out the piece of charcoal. Compare its shape and structure with the original wood.
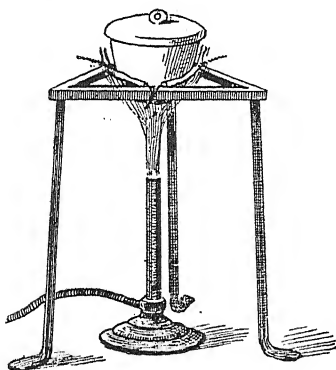

Fig. 20.—Tripod Stand and Crucible

EXPERIMENT 22.—*Estimation of moisture in coal.*

Weigh out about 3 gm. of powdered coal in a crucible, and dry it in an air-oven regulated to 105° C., for one hour. Allow to cool in a good desiccator and reweigh. The loss is moisture.

EXPERIMENT 23.—*To estimate* (1) *the volatile matter*; (2) *the fixed carbon*; (3) *the ash in coal.*

1. Two or three grams of coal, powdered and air-dried, are heated in a crucible provided with a closely fitting lid (fig. 20) for about 15 minutes, over the full flame of a good Bunsen burner. Cool and reweigh, the loss in weight being the volatile matter which has been expelled.

2. The crucible lid is then removed, and the coke burnt away entirely by the flame. Cool, replace the lid, and weigh again. The difference between this weight and the previous one gives the fixed carbon burnt off.

3. The residue left in the crucible consists of ash.

QUESTIONS ON CHAPTER XV

1. Explain why coal may contain 80 per cent of carbon, yet the material from which it was formed contained only 50 per cent of carbon.

2. Find the percentage of moisture in a sample of coal which gave the following results: Weight of empty crucible = 25·95 gm.; crucible + coal = 29·15 gm.; crucible and coal after heating to 105° C. for one hour = 29·07 gm.

3. From the following results, find (*a*) the percentage of volatile matter; (*b*) the percentage of fixed carbon; (*c*) the percentage of ash contained in the coal used. Weight of empty crucible = 27·85 gm.; crucible + coal = 30·95 gm.; weight after volatile matter is expelled = 30·02 gm.; crucible + residue, after fixed carbon is burnt off = 28·16 gm.

4. Explain fully how ash reduces the calorific value of coal.

5. How is charcoal made?

6. What are the disadvantages of peat as a fuel?

CHAPTER XVI

Properties and Uses of Coal

Uses of Coal.—The chief uses of coal are:

1. *For domestic fires.*

A freely burning bituminous coal is used, one which cakes being most economical.

2. *For steam-raising.*

A hard steam coal or semi-anthracite is most esteemed, as it has a high calorific value, produces little ash, and does not smoke.

3. *For industrial heating purposes.*

Where intense local heating is required, a fuel containing little volatile matter, such as anthracite, is employed. Where long flame is essential, the proportion of volatile matter which provides the combustible gases must be high.

4. *For gas-making.*

For making coal gas, a bituminous coal with a fair percentage of hydrogen is required.

5. *For coking.*

Bituminous coal is used.

Commercial Varieties of Coal.—These may be considered under the following heads:

1. *Cannel coal.*
2. *Bituminous coal.*
3. *Steam coal.*
4. *Anthracite.*

Cannel Coal

This variety differs in character from true bituminous coal. It is more compact, possesses little or no lustre, and does not show any banded structure. It contains more volatile matter than bituminous coal.

Bituminous Coal

There are several varieties of bituminous coal, differing considerably from one another in their chemical composition. Some varieties are caking coals while others are non-caking. They all possess the common property of burning with a smoky flame, and yielding on distillation volatile hydrocarbons and tar. Complete combustion of soft or bituminous coal, without objectionable smoke, is difficult to secure, even with considerable excess of air, unless a mechanical stoker is employed.

Steam Coal

Steam coal is a very wide term and includes all coal, except the strongly caking varieties and anthracite. Navigation coal is used for navigation purposes, and is of a less bituminous character than the steam coal in general use for manufacturing purposes. Smokeless steam coal is the valuable well-known Welsh variety. It is so low in volatile matter that there is no difficulty in burning it with little or no smoke.

Anthracite

Anthracite is the least widely distributed coal, and one of the most valuable. The most notable deposits are those of South Wales and Pennsylvania. It is hard and lustrous and does not soil the fingers. The percentage of ash is lower than in bituminous coal. The best grade of South Wales anthracite contains 93·5 per cent of carbon. Its calorific value is about 8700 calories (15,660 B.Th.U.).

Properties of Coal

Specific Gravity and Stowage Capacity.— The specific gravity of coal varies between 1·27 and 1·45, and only in exceptional cases will it fall outside these limits. The stowage capacity, or number of cubic feet per ton, will depend on the specific gravity and the size of the coal, the latter of which decides the relation of air spaces to solid.

Welsh coal = *40 to 42 c. ft. per ton.*
Newcastle coal = *45 c. ft. per ton.*
Scotch coal = *47 to 50 c. ft. per ton.*

Cohesion.—The resistance to breakage on handling is a most important property. Coal otherwise excellent is sometimes so soft that it is broken down during transport, with the production of so much small coal that its value is considerably lowered.

In shipment by the older methods of tipping, great crushing results, which, besides giving so much small coal, has a most important effect on the liability to spontaneous combustion.

Calorific Value.—This is perhaps the most important property of coal. The thermal value may be regarded as the sum of the heat units of the fixed carbon and the volatile hydrocarbons. The value of the former is practically constant for all varieties of coal, viz. 8000 calories (14,400 B.Th.U.).

Combustion of Coal

Theoretically, an average bituminous coal requires 11 lb. or 140 c. ft. of air per pound, but perfect combustion cannot take place without 20 per cent of excess, that is, say, 170 c. ft. of air per pound of coal. The combustible elements of coal consist entirely of carbon, hydrogen, and sulphur (omitting phosphorus), so that, if their combustion is completed, the flue gases should contain only carbon dioxide, water vapour, sulphur dioxide, and the large volume of nitrogen from the air used. Visible evidence of incomplete combustion is given by the formation of smoke.

The Smoke Problem

The smoke nuisance is not a new one, for when bituminous coal was first employed in England, about 1300, the smoke was pronounced such an annoyance

that the use of coal was for a time prohibited by law. It has been estimated that London loses, owing to its smoke, about half its sunshine in winter and one-sixth in summer. The metropolis consumes 15,000,000 tons of coal per annum, and about 385,000 tons of that amount are thrown into the atmosphere as smoke, that is, the air of London is polluted by over 1000 tons of soot per day, thus cutting off the sunshine, producing fogs, and making the buildings look grimy.

In this country it is the almost universal custom to use open fireplaces in our houses, and the coal that is burnt in these is of the soft or bituminous variety, which produces gas and tarry matter when heated. Now it is quite impossible to secure perfect combustion of soft coal in open grates, therefore in order to improve matters we must either alter our fireplaces or employ some other fuel. The alteration of the domestic fireplace, so as to secure the proper smokeless combustion of soft coal, is possible but expensive, and has not been carried out to any large extent. With regard to replacing bituminous coal by another fuel, chemical investigation has made it plain that the chief objection to soft coal is the large amount of tarry matter which it yields on heating. The use of anthracite (hard coal) and coke (coal deprived of its gas and tar) is debarred, on account of the great difficulty in igniting them, and also because, when they have been ignited, they burn without that bright flame which is part of the charm of the open fireplace. If solid fuel is to be burnt, what we require is one which ignites easily and looks cheerful, yet gives off no tarry matter when heated. These conditions are fulfilled to a large extent by "coalite", which may be described as half-coked coal. The general use of such a fuel would get rid of the smoke difficulty, but the custom of burning dirty, smoky coal will probably die hard. Another way of evading the production of smoke is to give up solid fuel altogether and burn gas; but here again, gas fires are less fascinating than coal fires, because they cannot be poked, and nothing can be thrown into them, hence they are disliked by many people. It is fairly certain, however, that the smoke problem will be solved in the future, by the use of half-coked coal or the extended use of coal gas. Much has already been done in lessening the smoke from factory

chimneys by regulating the air-supply, feeding in the fuel with mechanical stokers, and also by smoke-consuming devices.

Deterioration of Coal

Freshly mined coal undergoes a rapid loss in calorific value during the first week or two after its removal from the pit, many varieties of bituminous coal being able to absorb oxygen from the air. A process of slow combustion is thus set up, the heat from which is disseminated rapidly. For this absorption of oxygen to take place, the physical condition of the coal is the chief factor: its size, its hardness, its porosity.

Spontaneous Heating and Combustion of Coal ·

The oxidation of coal exposed to the air may lead to considerable heating, and possibly spontaneous ignition. In the case of large heaps of small coal, where a large surface is exposed to the air, this absorption of oxygen causes a slow rise of temperature. When this heating takes place at a distance from the surface, escape of heat is prevented.

As soon as the temperature of the mass reaches 120° C., carbon dioxide and water vapour make their appearance. After this the increase of temperature is accelerated up to about 275° C., when the rise becomes extremely rapid, until the ignition-point is reached, when active combustion is set up. Large surface, which means fineness of division, is essential to heating.

Coal Briquettes (Patent Fuel)

Bituminous coal will cohere under pressure when in a finely divided state, but the blocks are too fragile for commercial use, so that some binding material is necessary. Pitch from coal tar is generally employed for this purpose. In the manufacture of briquettes, the coal is reduced to a coarse powder, and then mixed with the broken pitch in a pug-mill. The mixture is then heated by steam and pressed.

EXPERIMENT 24.—*To determine the specific gravity of coal.*
Select a piece of coal about the size of a large walnut, and find its weight in air. Reweigh while completely immersed in water. From these weights find its specific gravity thus:

$$\frac{Weight\ in\ air}{Weight\ in\ air\ -\ Weight\ in\ water}.$$

QUESTIONS ON CHAPTER XVI

1. State the chief uses of coal, and indicate the variety most suitable in each case.

2. A piece of coal weighs 9·72 gm. in air, and 2·52 gm. when immersed in water. Find its specific gravity.

3. Why do household fires produce so much smoke? How could this smoke be prevented?

4. Explain why large heaps of small coal sometimes take fire.

5. What are steam coal, cannel coal, anthracite?

6. A railway wagon 15 ft. long and 6 ft. wide is filled to an average depth of 5 ft. with coal of storage capacity 45 c. ft. per ton. Find the weight of coal in the wagon.

CHAPTER XVII

Coking of Coal

COKE

Curiously enough, the destructive distillation of coal was carried on in England before the introduction of coal gas, but with the sole object of preparing coke, no attention being paid to the gas. The coke was required as a substitute for charcoal.

For many generations charcoal was a fuel of great industrial importance, because iron manufacturers used it in the blast-furnaces, to reduce the metal from its ores. About the middle of the eighteenth century the scarcity of fuel was beginning to be felt in England, and the increasing cost of charcoal caused iron-smelters to look round for a substitute, and thus it was that the production of coke from coal was started.

For smelting iron, a fuel poor in volatile matter is essential for the high calorific intensity required, and this is best furnished by coke, the porosity of which ensures sufficiently rapid burning. Although anthracite contains a low percentage of volatile matter, it fails as a metallurgical fuel, by reason of its density. As a consequence of the introduction of coke, with its high resistance to crushing in the furnace, and its rapid combustion with a hot blast at high pressure, it has been possible to increase greatly the size and output of blast-furnaces. By submitting a bituminous coal to a temperature of well over 1000° C., it loses practically the whole of its volatile constituents, which escape as gases and vapours, leaving behind a more or less hard cellular mass of coke. It may for practical purposes be regarded as carbon with the mineral

matter of the coal, that is the ash. The calorific value of well-carbonized dry coke is given by the formula

$$Calories\ per\ gramme = \frac{8100\ (100\ \% - ash\ \%)}{100}.$$

Properties of Blast-furnace Coke

Hardness.—Hardness is necessary to prevent losses in drawing the ovens, in handling, and in the furnace itself. The high temperature employed in coking the coal ensures this hardness.

Porosity.—The relative porosities of wood charcoal and coke are 2·5:1. Under modern blast-furnace conditions all coke is sufficiently porous to burn well.

Specific Gravity (Real and Apparent).—The real specific gravity of coke is the specific gravity of the coke substance, not including the pores.

The apparent specific gravity is the ratio of the weight of the whole coke, including pores, to that of an equal volume of water. This latter value is of great practical importance and lies between 1·2 and 1·9.

Ash.—A high percentage of ash lowers the calorific value, and also necessitates the use of additional flux, in order that it may be removed properly as slag. Coke frequently contains 8 per cent of ash.

Water Present.—The amount of water present will depend a great deal on the method of quenching, when the coke is drawn from the ovens; 4 to 5 per cent is common, but in good Durham coke it seldom exceeds 2 per cent.

Sulphur Present.—Most good coke contains less than 1 per cent of sulphur.

Coking of Coal

Coke is obtained as a by-product in the coal-gas manufacture. Gas coke, however, does not possess those properties so essential in metallurgical coke, being less dense and more fragile. Blast-furnace coke or oven coke is made in coke ovens, which are of two kinds:

1. *The beehive oven.*
2. *The by-product oven.*

Beehive Coke Ovens

At one time all the coke produced was made by these ovens. Though they are being replaced by by-product recovery ovens, they are still largely used in this country.

A beehive coke oven is a dome-shaped structure built of fire-brick, about 12 ft. in diameter and 7 ft. high. It is charged with
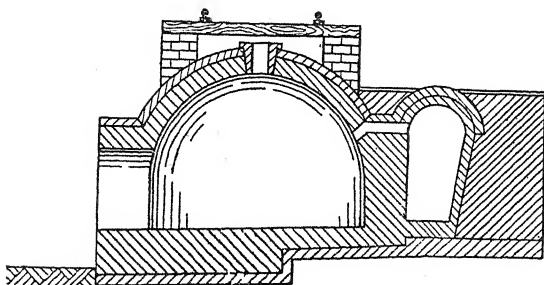

Fig. 21.—Beehive Coke Oven

coal from the top, to a depth of about 3 ft. To economize heat, they are built in two rows, back to back, with a common flue down the centre, the waste heat passing under boilers for raising steam. A false door is built up at the front, and a limited amount of air is admitted above the level of the coal, to burn the

vapours evolved. Carbonization takes place from the top downwards.

A beehive oven takes a charge of 6 tons of coal, the period of carbonization being about seventy-two hours. The valuable by-products contained in the coal are wasted in this type of oven, coke being the only product.

By-product Recovery Coke Ovens

The displacement of the old wasteful method of making coke by beehive ovens has been going on rapidly for a considerable time, the value of the by-products being generally recognized.

Practically all types of by-product coke ovens consist of long rectangular chambers, 30 to 35 ft. long, 6 to 7 ft. high, and 18 to 24 in. wide, closed by doors at each end. A number of ovens are built up side by side to form a battery (fig. 22). The coke is pushed out by a ram, applied at one end, and is quenched at the other end. The bottoms are heated (by combustion of some of the gas produced) by sole flues, and the sides by a suitable arrangement of flues built between adjacent ovens. The best results are obtained with coal of small size, large coal for coking being usually crushed and washed.

A modern retort oven deals with 40 tons of coal per week, this with a 72-per-cent yield giving about 30 tons of coke. Each oven takes a charge of about 7 tons of coal and carbonizes it in twenty-eight hours. A coal yielding 67 per cent of coke in a beehive oven will yield in a by-product oven 73 per cent of coke, and, in addition, tar, ammonia, and gas.

Recovery of By-products

The system most commonly employed is similar to that used in the coal-gas industry. This consists in condensing the tar and ammoniacal liquor, and then

washing the cooled gases with water to dissolve out the ammonia.

For gas-engine use the gases are afterwards cleansed by a process of filtration. Where benzene is to be recovered, the gases are washed with creosote oil, from which the benzene is recovered by distillation.

Special Forms of Coke

Coalite.—This special form of coke was introduced with the idea of providing a smokeless fuel, capable of being burnt easily in the ordinary domestic grate, and ignited in the usual manner with wood. The process by which coalite is prepared is similar to that of producing coke, only in this case the coal is distilled at a low red heat (400° C. or 750° F.). At this temperature all the tar and only part of the gas are expelled, so that the residue contains some inflammable gas, which causes it to ignite readily and burn with a smokeless flame.

How long our Coalfields will last

The combustible material stored up in the earth, although it is present in large quantities, is yet not inexhaustible, and in the interests of generations to come it is only right that we should avoid waste as far as possible. There is no likelihood of our coal supplies running short for some centuries to come, but we ought to remember that, in the matter of fuel consumption, the modern world is living on its capital.
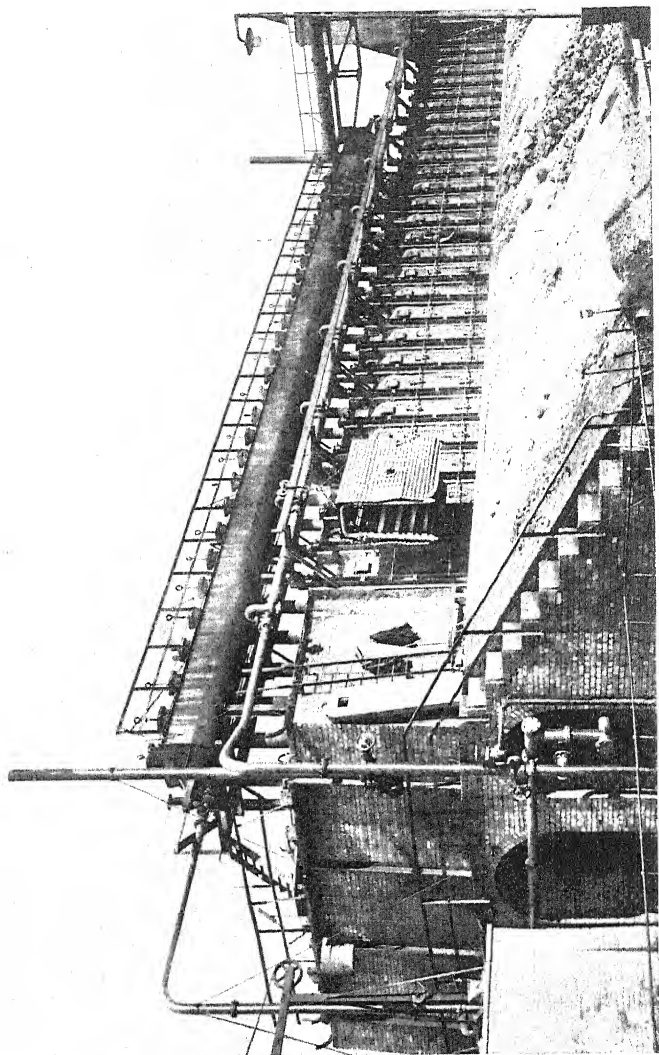
The Fuel of the Future

It is perhaps premature to trouble ourselves with a problem which is one for the men of science of the distant future.   So far as we can see at present, if our supplies of natural fuel—coal, peat, petroleum, natural gas—were exhausted, we are forced to the conclusion that fermentation is the only practical solution, thereby producing large quantities of alcohol.   This substance can be obtained with comparative ease from potatoes, wheat, beetroot, rice, and similar substances. By growing these common products of the soil, therefore, it is possible to obtain a substitute for natural fuels.

Average Thermal Values of Solid Fuels

Fuel.	Calories.	B.Th.U.
Anthracite	8700	15,660
Newcastle Coal	8400	15,120
Welsh Coal	8350	15,030
Derbyshire Coal	8120	14,616
Lancashire Coal	8110	14,598
Oven Coke	8000	14,400
Gas Coke	7900	14,220
Lignite	6000	10,800
Peat (dry)	5500	9,900
Wood (dry)	4700	8,460
Wood Charcoal	8000	14,400

QUESTIONS ON CHAPTER XVII

1. Find the heating power of coke containing 5 per ce of ash.

2. Why is it wasteful to carbonize coal in beehive co ovens?

3. Describe a by-product coke oven.

4. What is coke?   Describe the production of coke.

5. If a coking coal contains 2 per cent of ash, find the percentage of ash in the coke it produces, assuming there is a 72-per-cent yield.

6. Why is gas coke not suitable for smelting iron?

CHAPTER XVIII

B. Liquid Fuels

GROWING IMPORTANCE OF LIQUID FUEL

Until quite recent times it was generally understood that a liquid fuel was a heavy oil, capable of being burnt in place of a solid fuel for steam-raising, or heating purposes in metallurgical or other furnaces, but the term liquid fuel has acquired a much wider meaning since the introduction of the internal-combustion engine.   During recent years the rapid development of such engines, and their application to motor-cars, submarines, dirigible balloons, and aeroplanes, have completely revolutionized our ideas of locomotion.   Liquid fuels for external combustion have now to take a second place in importance for power purposes, the premier position being held by liquid fuels suitable for internal-combustion engines.

The former class has, however, played no small part in the development of our naval supremacy. To the splendid results obtained by oil-firing, combined with the use of turbines, must be largely attributed the marvellous power and speed of all types of ships in the leading navies of the world.
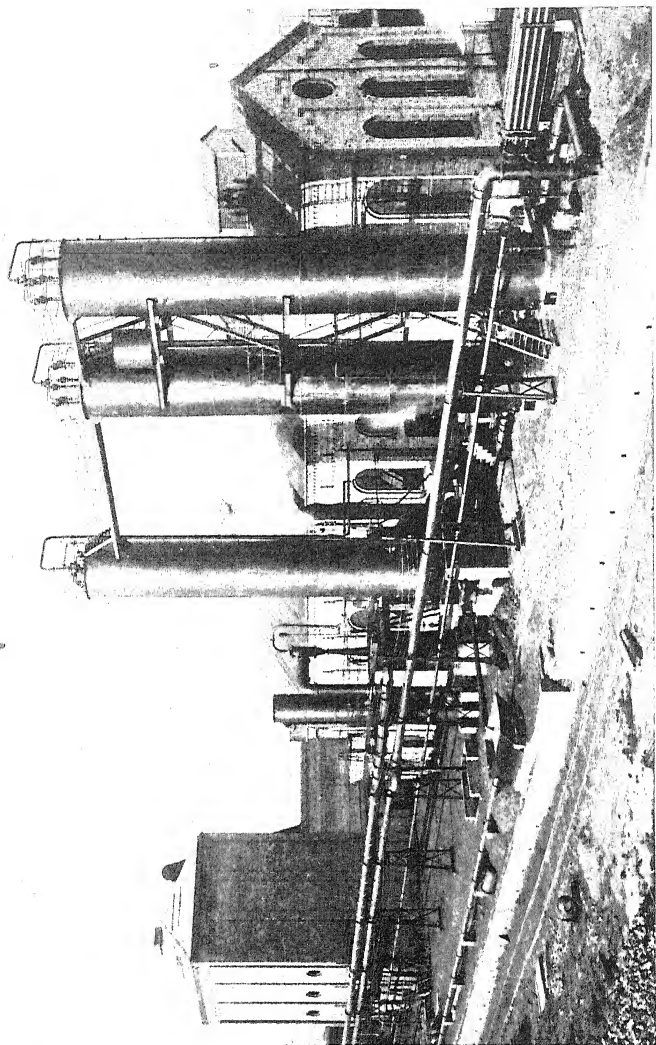
Classification

As indicated above, liquid fuels may be divided into two classes:

1. *Fuels suitable for external combustion* (*substitutes for solid fuels*).

2. *Fuels for internal-combustion engines.*

No hard-and-fast line can actually be drawn between the two classes, because an oil of high flash-point, suitable for external combustion, is equally suitable for use in engines of the Diesel type.

I. Liquid Fuels for External Combustion

Oil fuel is largely used for steam-raising both on sea and land, and also for a great many other purposes.

Liquid Fuel for Steam-raising

The advantages of oil fuel for steam-raising, as compared with solid fuel, are:

1. *High Calorific Value.*—1 lb. of oil fuel averages 19,500 B.Th.U. as compared with 15,000 B.Th.U. for 1 lb. of coal. The theoretical evaporative value of fuel oil is therefore about 20 lb.

2. *Low Stowage Capacity.*—1 ton of oil fuel averages 38 c. ft. as against 43 c. ft. for 1 ton of average coal. The high calorific value and low stowage capacity enable a greater number of heat units to be carried o stored, per cubic foot of space, than for coal, in the ratio of 1·5:1.

Further, oil can be stored in tanks, situated i

places where it would be impossible to store solid fuel.

3. *Easy Control of Consumption.*—The consumption of the oil is manipulated by opening or closing a valve, or by putting into action extra burners, or putting out of action burners which have been in use. By these simple operations any desired rate of steam production can easily be secured.
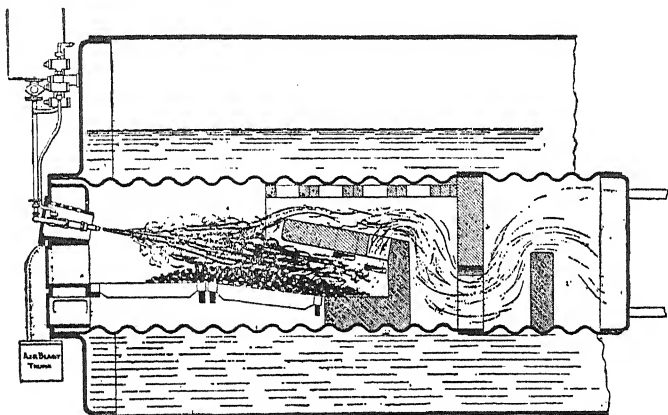

Fig. 24.—Oil Furnace as applied to a Steam Boiler

4. *Economy in Staff.*—The heavy labour of coal-trimming and handling is abolished, and therefore a great reduction of stoke-hole staff is possible. One man with oil fuel is equivalent to eight men with coal.

5. *Cleanliness.* — Bunkering with coal, especially on board ship, must always be a very dirty opera-tion. Oil can be pumped through suitable hose, directly into the tanks, without causing any dirt. Oils burn without residue, so that the cleaning of fires, handling and disposal of ashes, clinkers, &c., are obviated.

6. *Lesser Advantages.*—Amongst minor advantages may be mentioned:

 a. Non-deterioration of oil in storage.
 b. Absence of danger from bunker explosions.
 c. Lower stoke-hole temperatures.
 d. No corrosion of the boiler plates.
 e. Abolition of stoking.

Liquid Fuel for Other Purposes

The advantages of liquid fuel are not confined to steam-raising. Its high intensity of combustion, the ease with which a steady temperature can be maintained over a long period, and the ease with which it can be controlled, are favourable to its use in many metallurgical and other industrial operations.

The absence of ash, and the small amount of sulphur which most oils contain, also make it very suitable for many purposes. It has been successfully employed for melting metal for casting, in kilns for glazing, in muffles for enamel ware, for rivet heating, for glass melting and annealing, and for carbonizing electric lamp filaments.

Essentials of a Fuel Oil

1. *It should have a high calorific value.*
2. *Its flash-point should be high.*
3. *Must not be too viscous at ordinary temperatures, so that it may readily flow through pipes.*
4. *Should be as free from water as possible.*
5. *Should not contain much sulphur.*

Fuel Oil Specifications issued by the Admiralty

1. The oil must consist of liquid hydrocarbons, and may be either:

> *a*. Petroleum, or
> *b*. Shale oil.

2. Its flash-point must not be lower than 175° F.

3. The proportion of sulphur must not exceed 3 per cent.

4. The amount of water must not exceed 0·5 per cent.

5. The viscosity of the oil supplied must not exceed 2000 sec. for an outflow of 50 c. c. at a temperature of 32° F., as determined by Sir Boverton Redwood's Standard Viscometer (Admiralty type for testing Fuel Oil). In this instrument the oil flows through an agate tube 5 cm. long and 3·5 mm. diameter.

6. The oil must be free from earthy matter, and impurities likely to choke the burners.

Available Fuel Oils

The available fuel oils are:

1. The heavier portions of natural petroleum and shale oils.

2. Tar oils from coal distillation.

Petroleum Fuel Oils

These oils for burning consist of the portions remaining after the lighter oils have been sufficiently removed for the residue to have a high enough flash-

point. The yield of burning oil may be taken approximately as

20 per cent of the American crude oil.
60 per cent of the Russian crude oil.

Fuel Oils from Shale

Shale oil is the only fuel oil of high quality which is produced in Britain. It is the heavier oils, freed from solid paraffin, which are suitable for fuel purposes.

Tar and Tar Oils

Tar oils are of considerable importance in Great Britain, as they form the only possible native supply of fuel oils, with the exception of the shale oils. With the adaptation of the Diesel engine to such fuels as crude tar, and the increasing importance of benzene as a substitute for petrol, in high-speed internal-combustion engines, tar oils will increase in importance from the fuel point of view. The flash-point of tar from coal distilled in vertical retorts is from 100° to 115° F. The calorific value of coal tar is about 8800 calories (15,840 B.Th.U.).

Systems of Burning Fuel Oils

The oil should be as free as possible from suspended water and solids. When the oil is supplied to the burners by gravity, a pair of supply tanks are employed, into which the oil is pumped. Here it is heated by a steam coil, to promote the separation of water and increase the fluidity of the oil. Two systems of burning the fuel oils are in vogue:

1. *Vaporizing the Oil.*—For the perfect combustion of the oil it is essential that as perfect a mixture as possible with air should be made. Theoretically this is accomplished most easily with the oil vapour, but it is not practicable to vaporize properly the heavier fuel oils, as the high temperature necessary leads to "cracking" of the oil, and the formation of deposits of carbon in the vaporizer. This method can be applied in the case of kerosene.

2. *Spraying the Oil.*—With the heavier oils, such as are generally employed, conversion into as fine a mist or spray as possible enables proper admixture of air to be attained. Various forms of atomizers, sprayers, or burners, as they are called, are employed. They are known as steam, air, and pressure atomizers, and the well-known types of each kind act quite efficiently.

For the supply of oil to the atomizers in the steam and air systems it is only necessary to have a feed tank or tanks at a sufficient height to give the required flow, and a pump for lifting the oil into the tanks.

a. Steam Atomizers.—The steam atomizer is largely used where the oil fuel is used for firing boilers. The steam should be superheated and at as high a pressure as possible. About 4 per cent of the steam generated in the boiler is used by the sprayer, but with heavy tar oils a higher percentage is required.

b. Air Atomizers.—The simple form shown in fig. 25 has been very successful both for steam-raising and for general industrial purposes, such as glass furnaces, &c. With this burner the combustion is quite smokeless. It will be seen that two streams of air act on the oil; these are both supplied from the same air pipe, which branches a short distance from the burner. To spray 1 lb. of oil, about 52 c. ft. of

air at 18 lb. per square inch pressure are required.

c. Pressure Atomizers.—These are of two kinds—
(1) those which consist of a jet of fluid oil, at high velocity, impinging upon a fixed knife-edge, which
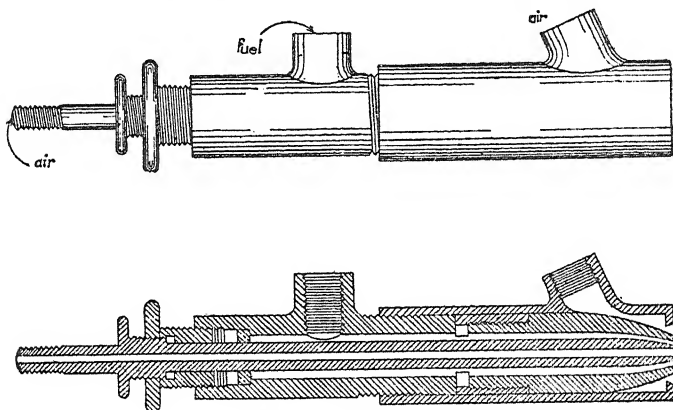

Fig. 25.—Air Atomizer

causes it to break into spray, and (2) those in which the oil is broken up by centrifugal action.

QUESTIONS ON CHAPTER XVIII

1. For what purposes can liquid fuel be used as a substitute for coal?

2. Give the advantages of liquid fuel over solid fuel for steam-raising.

3. The specific gravity of an oil fuel is 0·940. Find in cubic feet per ton its stowage capacity.

4. State the essentials of a high-class fuel oil.

5. What are the different methods of spraying an oil fuel into a furnace?

6. Describe the principle of an air sprayer?

CHAPTER XIX

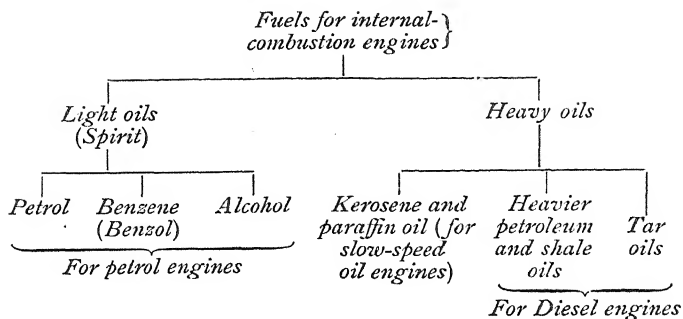# II. Liquid Fuels for Internal-combustion Engines

Internal-combustion engines may, for considering the various fuels, be classified as:

1. *High-speed engines*, requiring an easily vaporized spirit or oil;

2. *Slow-speed engines*, in which the oil is either vaporized by heat before entering the cylinder, or it is vaporized in the cylinder, or it is injected as a spray into the cylinder after the temperature of the air in the cylinder has been raised by compression, as in the Diesel engine. In this case the temperature produced by compression is high enough to ignite the oil.

Classification of Fuels for Internal-combustion Engines

The suitability of the various oils for the different types of engines depends largely on their vapour pressures. For the high-speed engine (petrol motor) the fuel must have a high vapour pressure at ordinary temperatures, so that it may readily give an explosive mixture with air in the carburettor. In engines of the Diesel type the ignition-point of the oil is the chief factor.

The liquid fuels for internal-combustion engines may be classified as follows:

Fuels for internal-
combustion engines

Light oils
(Spirit)

Heavy oils

Petrol   Benzene   Alcohol
(Benzol)

For petrol engines

Kerosene and
paraffin oil (for
slow-speed
oil engines)

Heavier
petroleum
and shale
oils

Tar
oils

For Diesel engines

Light Fuels (including Alcohol) for Internal-combustion Engines

These are volatile, mobile liquids, and are used for high-speed engines. They include petrol, benzol (commercial benzene), alcohol.

Petrol

This important fuel is obtained by the redistillation of the petroleum spirit obtained from crude petroleum oil. A further small supply is also available from the naphthas obtained from crude shale oil. It consists of the more volatile portions of the petroleum spirit or shale naphtha, and distils completely between 60° C. and 150° C.

Composition.—It contains 84 per cent of carbon and 16 per cent of hydrogen.

Specific Gravity.—Formerly petrol was commonly known as 680 spirit, as its specific gravity was 0·680. Nowadays, however, spirit of specific gravity 0·760 is quite suitable, owing to the introduction of spray carburettors. Its specific gravity may therefore be between 0·680 and 0·760.

Calorific Value.—

Gross = 11,200 calories (20,160 B.Th.U.).
Net   = 10,400 calories (18,720 B.Th.U.).

The Petrol-air Mixture.—The theoretical amount of air for the complete combustion of petrol is shown in the following table:

	Pounds of Air.	Cubic Feet of Air.	
		At 0° C.	At 60° C.
Per pound of petrol	15·25	187	197
Per gallon of petrol	109·5	1346	1420

Benzene (Benzol)

Benzene was discovered by Faraday in 1825. It is a mobile, colourless liquid which freezes at 6° C., but the pure liquid is too expensive to be used as a fuel. The liquid used for this purpose is a commercial mixture, commonly known as "benzol".

Benzol is distilled from the coal tar obtained at the gasworks, and large quantities are also extracted in the production of coke by the by-product ovens. Benzol is classed as 90 or 50 per cent, which indicate the percentage of the liquid distilling below 100° C. Benzol 90 per cent is the quality usually employed in this country as a petrol substitute. This liquid has proved a most successful fuel in internal-combustion engines, where it may be used without altering any of the existing arrangements for petrol.

Its gross thermal value is 9860 calories (17,750 B.Th.U.), its net value being 9500 calories (17,100 B.Th.U.).

Alcohol

Although not a fuel in the commercial sense in Great Britain, it has a great many advantages as

a fuel. For alcohol to become a practical fuel in this country, a great many of the restrictions imposed at present will have to be relaxed. Its practical value has been already proved, for it has taken a place as a commercial fuel in the United States, France, and Germany. Alcohol is the only fuel which can be produced without using existing fuel substances.

Advantages of Alcohol.—

1. Great safety, on account of its low degree of volatility and high flash-point ($17°$ C. = $63°$ F.).

2. Its vapour is only half as heavy as that of petrol, so that it cannot creep and accumulate in dangerous places on low levels.

3. Its vapour mixes in all proportions with air.

4. Burning alcohol can be extinguished with water.

5. Its composition is very uniform.

Methylated Spirit (Denatured Alcohol).—This form of alcohol contains, as a rule, 90 per cent of spirit, to which has been added something for rendering the alcohol unpalatable. In this country 10 per cent of methyl alcohol (wood spirit) and a small quantity of a paraffin hydrocarbon are added. The latter causes turbidity when the methylated spirit is diluted with water.

Properties of Petrol, Benzol (90 per cent), and Methylated Spirit.

	Petrol.	90 per cent Benzol.	Methylated Spirit.
Specific Gravity	0.680 to 0.760 C.	0.883	0.82
Boiling Range	60° to 150° C.	80° to 120° C.	80° to 110° C.
Freezing-point	− 120° C.	+ 6° C.	− 110°
Co-efficient of Expansion {	0.0008 per ° C.	0.0014 per ° C.	0.0011 per ° C.
	0.00045 per ° F.	0.00077 per ° F.	0.00062 per ° F.
Calorific Value :			
B.Th.U. per pound (gross)	20,160	17,750	11,320
B.Th.U. per pound (net)	18,720	17,100	10,350
B.Th.U. per gallon (gross)	144,760	156,700	92,820
B.Th.U. per gallon (net)	135,300	150,000	84,900

Comparison of Petrol, Benzol, and Alcohol

A large number of petrol engines have been run with every success on benzol (90 per cent) as the sole fuel, the only alteration being the admission of a little more air than for petrol. The chief difficulty with benzol is a little trouble in starting in cold weather, and there is also the possibility of the liquid freezing at low temperatures, but mixing with petrol obviates these difficulties.

From exhaustive trials made in the United States with alcohol, the conclusions arrived at were:

1. That any petrol engine of the ordinary type can be run on alcohol, without alteration.

2. The maximum power is usually greater with alcohol.

3. The engines are more noiseless than with petrol.

4. The fuel consumption per brake horse-power with a good, small stationary engine is 1 lb. with alcohol, as against 0·7 lb. with petrol.

Oils for Slow-speed Internal-combustion Engines

The oils so largely employed for slow-speed internal-combustion engines are those sold mainly for general illuminating purposes (kerosene and paraffin oil), having flash-points higher than 73° F., although some special oils, intended for use solely in such engines, are now on the market. The usual temperature over which such oils are collected is from 150° C. to 300° C. The use of these oils for power purposes has many advantages over petrol, such as:

1. They are more plentiful, as they form a much higher percentage of the total distillate obtained from the crude oil.

2. Their flash-points are so high that no special

precautions are required in their storage and distribution.

3. Their price is low compared with petrol.

Owing to their relatively low vapour pressures it is impossible to form an explosive mixture in the same way as with a petrol carburettor, and heat has to be applied to vaporize the oil. Without special care this may lead to "cracking" of the oil, and the almost certain appearance of a carbon deposit.

The calorific value of petroleum (kerosene) is 10,800 calories per kilogram, or 19,440 B.Th.U. per pound, or 162,000 B.Th.U. per gallon.

Heavier Oils for Diesel Engines

In this class are included those oils more particularly suitable for the Diesel or semi-Diesel type of engine. They include:

1. *Petroleum heavier than the illuminating oils.*
2. *Gas oils intermediate between the illuminating oils and lubricating oils.*
3. *Heavier shule oils, containing very little paraffin wax.*
4. *Heavy tar oils.*
5. *Crude tar.*

A high-class oil of this type has a gross calorific value of 10,800 calories, or approximately 19,500 B.Th.U. per pound.

The Diesel Oil Engine

In this engine, pure air is drawn into the cylinder, and compressed by the piston to about 500 lb. per square inch pressure, the temperature rising to almost 600° C. (due to compression). The oil is then sprayed

into the cylinder, by a blast of air, at a higher pressure than that in the cylinder. Combustion takes place, as the temperature of the compressed air is above the ignition-point of the oil.

Tar Oil and Crude Tar

Although the heavy petroleum and shale oils are undoubtedly the most suitable for the above engines, considerable success has attended the use of tar oils and crude tar.

Average Thermal Value of Liquid Fuels

Fuel.	Calories	B.Th.U.
Petrol	11,200	20,160
Benzol (90 per cent)	9,860	17,750
Absolute Alcohol	7,184	12,930
Methylated Spirit	6,290	11,322
Petroleum (Fuel Oil)	10,800	19,440
Shale Oil (Power Oil)	10,800	19,440
Crude Tar	8,800	15,840

QUESTIONS ON CHAPTER XIX

1. Classify the fuels suitable for internal-combustion engines.

2. What are petrol, benzol, and methylated spirit?

3. What are the advantages and disadvantages of benzol and alcohol when used as substitutes for petrol for running high-speed internal-combustion engines?

4. The gross calorific value of 90 per cent benzol is 9860 calories per gramme. Taking its specific gravity as 0·883, find its gross thermal value in British Thermal Units per gallon.

5. Why is alcohol not used as a liquid fuel in this country?

6. When should the gross calorific value of a fuel be used? Give reasons for your answer.

CHAPTER XX

C. Gaseous Fuels

GASEOUS FUELS OF HIGH CALORIFIC VALUE

The important position which gaseous fuel has occupied for several years is sufficient proof of its value as a heating agent and for power purposes. It is a very valuable method of obtaining power at a cheap rate. Gaseous fuel has also played an important part in saving the natural fuel supplies of this country.

Advantages of Gaseous Fuel

The chief advantages of gas-firing over direct coal-firing are:

1. *The highest temperatures and complete combustion are attainable.*

2. *Furnace temperature is under absolute and easy control.*

3. *Black smoke is eliminated.*

4. *Labour (coal and ash handling, &c.) is much reduced.*

5. *A reducing or oxidizing flame is obtained at will.*

6. *Output of furnace is increased.*

7. *A saving of fuel is effected, and, in addition, cheaper-quality fuel can be used.*
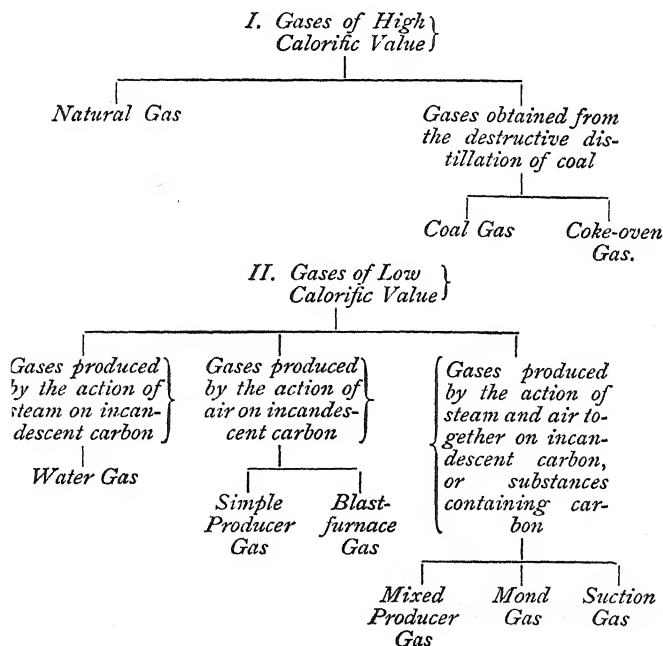
8. *By recuperation, a large amount of heat, otherwise lost in the waste gases, is returned to the furnace.*

Classification of Gaseous Fuels

There are two main classes of gaseous fuels:

1. Gases of High Calorific Value.—These gases include natural gas and those obtained by the destructive distillation of coal. Natural gas, however, is of no importance in this country.

2. Gases of Low Calorific Value.—This class includes the gases obtained by the action of (1) steam alone, (2) air alone, (3) steam and air together, on substances containing carbon.
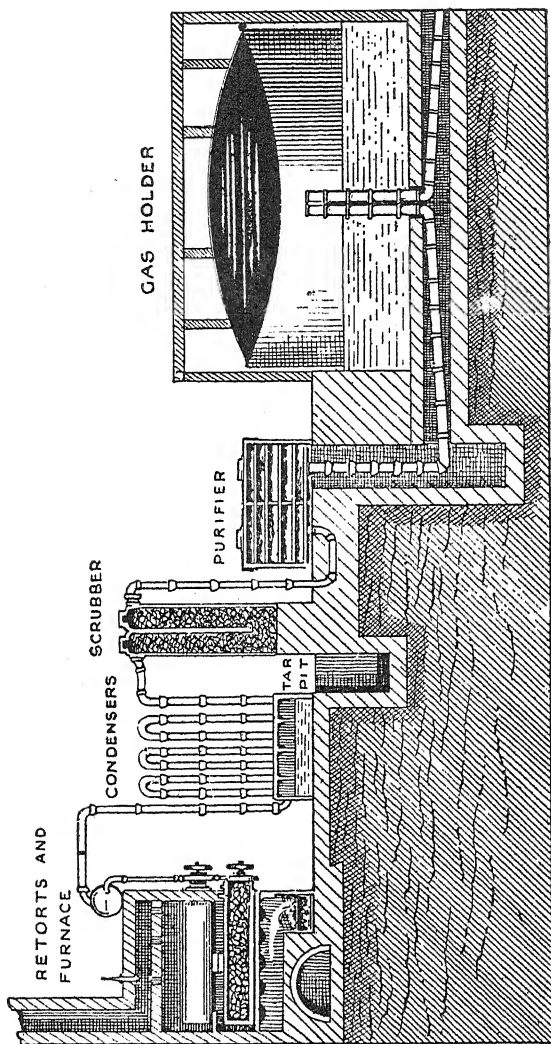
I. Gases of High Calorific Value

    Natural Gas

    Gases obtained from the destructive distillation of coal

    Coal Gas   *Coke-oven Gas.*

II. Gases of Low Calorific Value

Gases produced by the action of steam on incandescent carbon

    Water Gas

Gases produced by the action of air on incandescent carbon

    Simple Producer Gas   *Blast-furnace Gas*

Gases produced by the action of steam and air together on incandescent carbon, or substances containing carbon

    Mixed Producer Gas   *Mond Gas*   *Suction Gas*

RETORTS AND FURNACE   CONDENSERS   SCRUBBER   PURIFIER   GAS HOLDER   TAR PIT

Fig. 26.—Coal-gas Plant

I. Gaseous Fuels of High Calorific Value

Natural Gas

Occurrence.—The enormous quantities of this gas obtained in the oil-producing regions of the United States are of great importance. In the West Virginia Oilfields 1300 million cubic feet are evolved daily, of which only one million cubic feet are utilized. Some years ago natural gas was struck at Heathfield in Sussex.
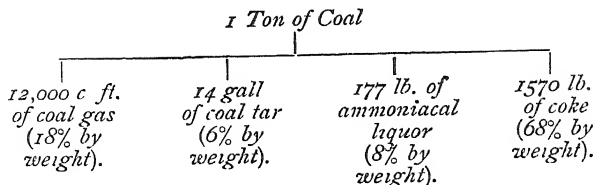
Composition.—The percentage of methane (marsh gas) in natural gas is always high, and in a large number of cases it is over 90 per cent. Hydrogen is also present to the extent of 1 or 2 per cent, though in a few cases it has exceeded 20 per cent. The percentage of non-combustible gases is low.

Calorific Value.—Its gross calorific value averages about 1000 B.Th.U. per cubic foot, its net value being about 900 B.Th.U. per cubic foot, the gas in each case being measured at normal temperature and pressure.

Coal Gas

For the greater part of a century the use of coal gas was confined to illumination. The development of the gas engine, and the extended use of coal gas for domestic heating purposes, have made it an important fuel.

Production of Coal Gas.—It is produced by the destructive distillation of gas coal at high temperatures, the average yield being

1 Ton of Coal

12,000 c ft. of coal gas (18% by weight).	14 gall of coal tar (6% by weight).	177 lb. of ammoniacal liquor (8% by weight).	1570 lb. of coke (68% by weight).

The quantity of coal gas produced is largely augmented by the addition of carburetted water gas, as 11 per cent of the coal gas used in this country consists of the above gas for enriching purposes

Composition.—Modern coal gas contains on the average:

Hydrogen	 53	per cent.
Methane	 31	,,
Acetylene, &c.	... 3	,,
Carbon monoxide	... 8	,,
Carbon dioxide and } Sulphur dioxide }	1·5	,,
Nitrogen, Oxygen, &c.	3·5	,,

The constituent gases may be divided into:

1. *Heating gases.* (*Hydrogen, methane, carbon monoxide.*)
2. *Diluting gases.* (*Nitrogen, oxygen.*)
3. *Impurities.* (*Carbon dioxide, sulphur dioxide.*)
4. *Illuminating gases.* (*Acetylene, &c.*)

Calorific Value. — Its net calorific value is 125 Kgm. calories per cubic foot. ($125 \times 2·2 \times 1·8 = 495$ B.Th.U. per cubic foot.)

Coke-oven Gas

Coke-oven gas approximates closely to coal gas in composition and calorific value. As a rule it contains more diluting gases, because of the difficulty in preventing air from entering the ovens; but when this is avoided, the gas obtained has practically the same composition and thermal value as the coal gas from the gasworks. Each ton of coal carbonized by the by-product ovens yields 10,500 c. ft. of gas, whose calorific value is 500 B.Th.U. per cubic foot.

With the regenerator type of by-product oven, from 50 to 60 per cent of spare gas can be obtained, for purposes other than the heating of the ovens, and can be used for generating power in gas engines and town lighting. A battery of ovens of this design has been erected at Newport Ironworks (N. Yorks.), belonging to Sir B. Samuelson & Co., Ltd., who are supplying the town of Middlesbrough with gas for power, lighting, heating, and all domestic purposes.

Supposing that only half the total coal which is coked for metallurgical use is carbonized in by-product coke ovens, it is evident that a very large amount of gas is available for conversion into electric energy.

Methods of Burning

Three systems may be used for burning coal gas and coke-oven gas, all of which depend upon obtaining the well-known non-luminous flame by mixing the gas with a certain proportion of air:

1. By the use of gas at the pressure of the mains, with air at atmospheric pressure. This system involves the use of burners of the ordinary Bunsen type.

2. By the use of gas at the pressure of the mains, with an air-blast under pressure. The burners in this case are on the blowpipe principle.

3. By the use of gas at high pressures with air at atmospheric pressure. This method is the one most favoured.

EXPERIMENT 25.—*To obtain the products of distilling coal.*
Pack a hard-glass bent tube loosely with small fragments of bituminous coal. Connect the tube to a pneumatic trough as shown in fig. 27. Then heat the tube as in making charcoal from wood. Crude coal gas, which burns with a luminous,
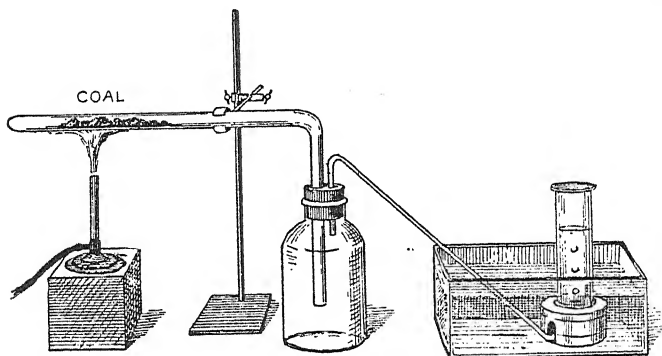

Fig. 27.—Apparatus for collecting the Products of the Distillation of Coal

smoky flame, and possesses an unpleasant odour, will be collected in the gas jar. A watery liquid, possessing a faint odour of ammonia, together with tarry matter will condense in the bottle. Allow the air to be expelled from the apparatus before collecting the gas.

QUESTIONS ON CHAPTER XX

1. Make a complete classification of gaseous fuels.

2. Name the constituents of coal gas and coke-oven gas. Classify these constituents.

3. Name the products of the destructive distillation of coal.

4. What are the advantages of gaseous fuel as compared with solid fuel?

5. Why is a blowpipe flame hotter than a Bunsen flame?

6. One cubic foot of coal gas can raise the temperature of 125 Kgm. of water through 1° C. Taking 1 Kgm. = 2·2 lb., find the number of pounds of water which can be heated 1° F. by 10 c. ft. of coal gas.

CHAPTER XXI

II. Gaseous Fuels of Low Calorific Value

The production of these gases depends upon the fact that the carbon in solid fuels which are rich in carbon, can be converted into carbon monoxide by the action of steam alone, or air alone, or by a mixture of steam and air. The amount of heat available from a given weight of solid fuel is the same whether the fuel is burnt directly in a grate or is used indirectly by first converting the fuel into gases, and then burning the gases. Better results are obtained, however, with the gaseous fuel than with the solid fuel.

Gaseous Fuels of this Class

The fuels of this class which are used for heating and power purposes are:

1. *Water gas.*

2. *Simple producer gas (air-coke gas and blast-furnace gas).*

3. *Mixed producer gas, which is a mixture of 1 and 2. (Water gas and air-coke gas mixed together, Mond gas, suction gas.)*

Water Gas

By passing a current of steam through a column of coke or hard coal heated to incandescence (900° C.), a combustible gas known as water gas is produced, its name having reference to the fact that water is required for its production. The reaction is:

$$C\ (incandescent) + H_2O\ (steam) = CO + H_2.$$
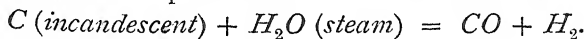
Equal volumes of carbon monoxide and hydrogen are produced. If steam be passed through a column of coke at a lower temperature (500° C.) the following is the reaction:

$$C + 2\ H_2O = CO_2 + 2\ H_2.$$
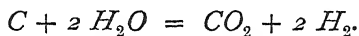
One-third of the total volume of gas produced in this case consists of the incombustible gas carbon dioxide.

Production of Water Gas.—The solid fuel (coke or hard coal) is first heated to high incandescence by an air blast, after which the steam is passed through it until the temperature is reduced to a point at which good gas cannot be obtained. The air blast is then blown through again, followed by the steam. This process, therefore, requires alternate "blows" with air, and "runs" of steam during which the gas is produced, and it is therefore an intermittent one. The production of water gas per ton of coke is from 35,000 to 40,000 c. ft.

Calorific Value.—Its heating value is about 310 B.Th.U. (gross) or 280 B.Th.U. (net) per cubic foot.

Uses of Water Gas.—This gas, as produced above, is known as plain water gas or blue water gas, from the colour of its flame. Plain or blue water gas is of great service in many heating operations, because when burnt it gives a very high flame temperature.

Under ordinary conditions of burning its flame temperature is about 1600° C. (nearly 3000° F.).

The chief uses of water gas are:

1. For making carburetted water gas.
2. For furnaces for heating drop-forgings and stampings.
3. For melting metal.
4. For special welding processes.
5. For glass-melting and cement kilns.
6. For the production of pure hydrogen. By cooling water gas to a low temperature, the carbon monoxide can be liquefied and hydrogen obtained.

Carburetted Water Gas

The principal use of water gas is for making carburetted water gas. To produce this gas, suitable mineral oils are "cracked" by heating to a high temperature. The resulting oil gas of high illuminating power is then mixed with the non-luminous water gas, and the mixture, which is known as carburetted water gas, is added to coal gas to enrich it, or increase its illuminating power. The manufacture of carburetted water gas for enriching coal gas, is now a most important operation in the coal-gas industry.

Simple Producer Gas

(*Air-coke gas or Siemens Gas*)

By passing a current of air through a column of coke heated to a high temperature, carbon monoxide is obtained, diluted with nitrogen. At the end of the column where the air enters, the carbon unites with oxygen, forming carbon dioxide, but this compound, as it is swept forward through the rest of the heated column, gives up half its oxygen to the coke, and

carbon monoxide is formed. The carbon monoxide escaping from the column of coke, is mixed with the nitrogen from the air which was sent in at the other end, and passes through the coke unaltered.

Simple producer gas contains approximately two-thirds of its volume of nitrogen, which is not a combustible gas. This air-coke gas, or generator gas, as it is called, has therefore a very low calorific value.

Uses of Air-coke Gas.—This gas is cheaply made and serves as an excellent fuel for glass-melting, brick-burning, heating of retorts and similar operations.

Blast-furnace Gas

Enormous quantities of gaseous fuel of low thermal value are evolved daily, during the reactions in the ordinary blast-furnace used for smelting iron. Formerly iron was obtained from its ores by means of the old open-throated furnaces, and the gas burned to waste. With the introduction of hot blast, a portion of the heat of the waste gases was returned to the furnace in the blast, and another portion was used for raising steam for the blowing-engines for operating the plant. This method
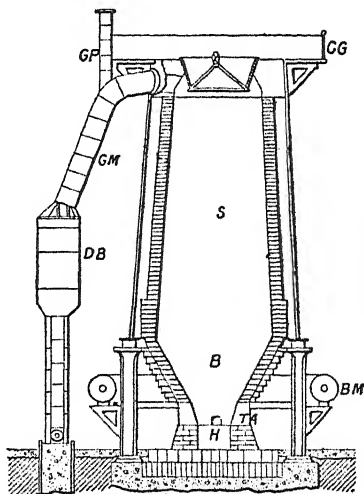

Fig. 28.—Typical Blast-furnace

s, Shaft. b, Bosh. h, Hearth. ta, Tuyere opening. bm, Blast main. cg, Charging gallery. gm, Gas main. db, Dust box. gp, Waste-gas pipe.

was not economical, so that nowadays large gas-engines which use the blast-furnace gas direct, are employed for supplying the blast and for generating electrical energy.

On the North-East Coast large quantities of coke-oven gas and blast-furnace gas are used for generating electricity, which is distributed over a large area. Blast-furnace gas must be cleansed before use in gas-engines.

Composition.—The following figures give the average composition when coke fuel is employed in the furnace:—

Nitrogen	*60 per cent.*	
Hydrogen	*2*	*,,*
Carbon monoxide	*28*	*,,*
Carbon dioxide	*10*	*,,*

Calorific Value.—Its thermal value is about 105 B.Th.U. per cubic foot.

Mixed Producer Gas

In most cases of producer practice, both steam and air are sent up through the heated column of coke, to convert the solid fuel into gaseous fuel. In this case a mixed gas, partly water gas and partly air-coke gas, is obtained, the gaseous product consisting of carbon-monoxide, hydrogen, and nitrogen.

As this process is continuous, and not intermittent, as in the case of water gas, it is almost always used nowadays.
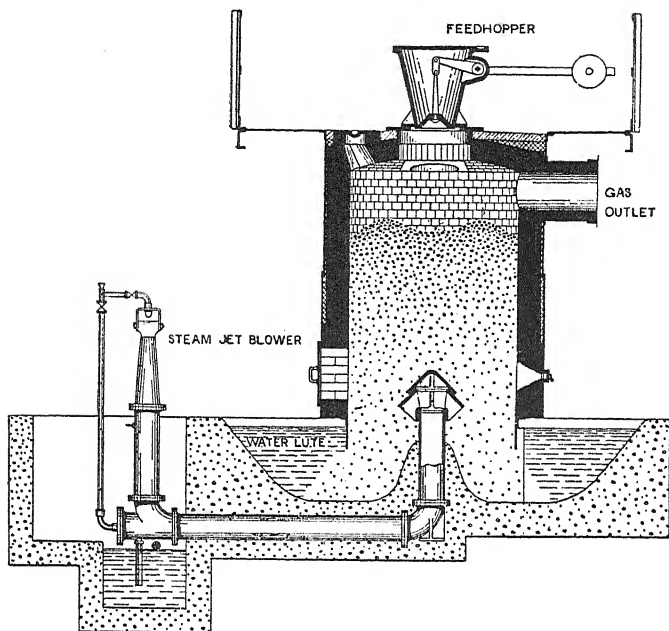
Fig. 29.—Gas Producer (Central Blast)

Fuels for the Production of Mixed Producer Gas

The variety of fuels which have been successfully used in gas producers covers nearly all substances containing carbon, from coke and high-class anthracite to colliery refuse or coal slack containing nearly 50 per cent of ash. It also includes lignite, peat, wood-waste, spent tan, coco-nut shells, &c.

The design of the plant is least complicated when the gas leaving the producer is the pure mixture of water gas and air-

coke gas. The simplest form of gas producer will therefore be that using coke or anthracite.

Mond Gas

When bituminous coal is used in the producer, the tar vapours which accompany the gas are of great advantage in metallurgical operations, because they are added to the calorific value of the gas. Gas produced in this way is known as Mond gas, after Dr. Ludwig Mond, F.R.S., to whom the process is due.

Mond gas is suitable for power purposes (in gas-engines) and heating purposes (furnaces, boiler-firing, &c.). When used for steel furnaces it passes directly from the producer to the furnace in a hot state, containing its tar vapours. One ton of good rough slack produces about 140,000 c. ft. of Mond gas. When bituminous coal or slack is employed, the ammonia is generally recovered by an ammonia-recovery plant, worked in conjunction with the gas plant.

Suction Gas

This gas is used as a fuel for gas-engines, and derives its name from the fact that the suction or charging stroke of the gas-engine tends to create a vacuum in the producer. The atmospheric pressure, as a consequence, forces air into the generator at defined points, carrying with it steam or water vapour. In other words, the charging stroke of the engine draws, through the gas generator, the air and water vapour.

Average Thermal Values of Gaseous Fuels

The calorific values in the following table are calculated from the specific gravity of each gas, to calories per gramme and B.Th.U. per pound, so that
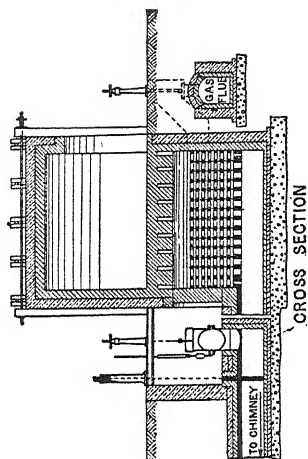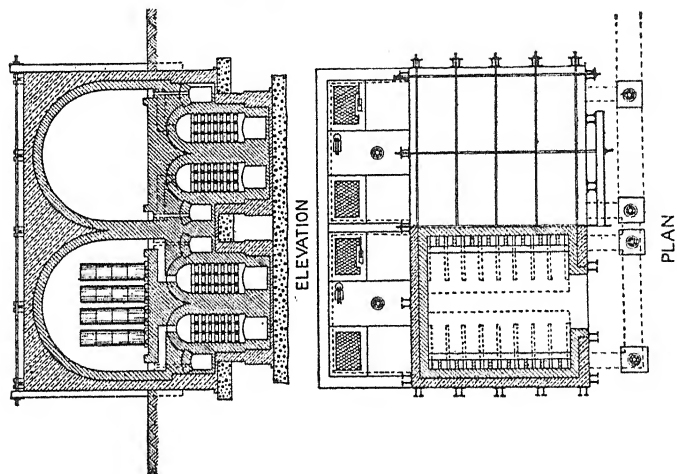
CROSS SECTION

GAS FLUE

TO CHIMNEY

ELEVATION

PLAN

Fig. 30.—Gas-fired Furnace for Annealing
Malleable Castings, &c.

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the values may be compared with those of solid and liquid fuels.

Fuel.	Calories per gramme.	B.Th.U. per pound.
Natural gas ...	12,000	21,600
Coal gas ...	10,600	19,080
Water gas ...	4,430	7,974
Air-coke gas ...	540	972
Blast-furnace gas	528	950
Mond gas ...	1,400	2,520

Questions on Chapter XXI

1. What is water gas and how is it produced?

2. How is carburetted water gas made and what is it used for?

3. What is Mond gas? How is it produced? State its uses.

4. To what uses is blast-furnace gas applied?

5. Name the solid fuels which can be employed for the production of generator gas.

6. When 1 lb. of pure carbon combines with $2\frac{2}{3}$ lb. of oxygen to form carbon dioxide, 8100 heat units are developed, but when the same weight of carbon unites with $1\frac{1}{3}$ lb. of oxygen to form carbon monoxide, only 2400 heat units are developed. Find the number of heat units developed when $2\frac{1}{3}$ lb. of carbon monoxide burn to form carbon dioxide.

ANSWERS

Chapter I

3. 144 lb. hydrogen.
   1152 lb. oxygen.

Chapter II

4. 57·9 lb. per cubic foot.

Chapter III

2. 1·34 tons per square inch.
5. 473·34 tons.

Chapter IV

2. Soya beans = 0·9 tons oil.
   Hemp seed = 1·5 tons oil.
   Walnut kernels = 3 tons oil.
   Poppy seed = 2·25 tons oil.
   Linseed = 1·75 tons oil.
4. 244·5 gall.

Chapter V

4. 924.
6. 91·6 Kgm.

Chapter VI

6. 14·4 c. c.

Chapter VII

6. 0·865.

Chapter VIII

6. 25·8 tons.

Chapter IX

6. 0·843.

Chapter X

6. $24\frac{8}{9}$ gall.

Chapter XII

6. 1:14·3.

Chapter XIII

6. 18,000 B.Th.U.

Chapter XIV

2. 11,268 calories, or 20,282 B.Th.U.
3. 7188 calories, or 12,938 B.Th.U.
4. 7790 calories, or 14,022 B.Th.U.
5. 12,290 calories, or 22,122 B.Th.U.
6. 156·57 lb.

Chapter XV

2. 2·5 per cent.
3. (*a*) 30 per cent volatile matter.
   (*b*) 60 per cent fixed carbon.
   (*c*) 10 per cent ash.

Chapter XVI

2. 1·35.
6. 10 tons.

Chapter XVII

1. 7695 calories.
5. $2\frac{7}{9}$ per cent.

Chapter XVIII

3. 38·1 c. ft. per ton.

Chapter XIX

4. 156,715 B.Th.U. per gallon.

Chapter XX

6. 4950 lb.

Chapter XXI

6. 5700 heat units.